Near-threshold Production and Energy-Dependent Electromagnetic Form Factors of Λ_c^+

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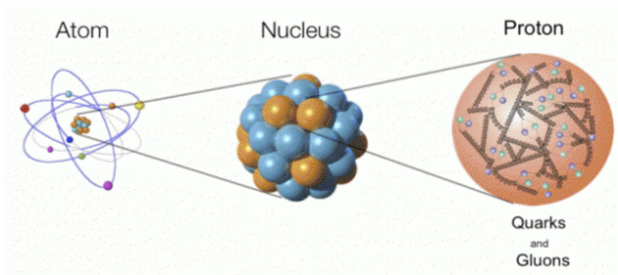
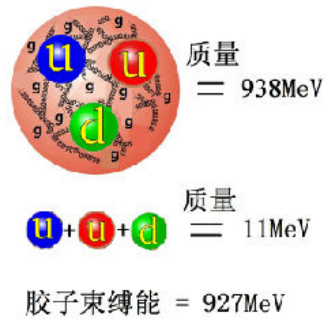
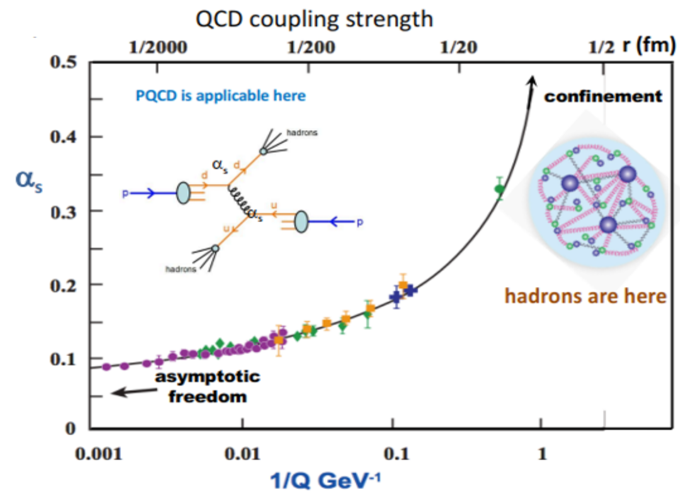
Electromagnetic form factors (EMFFs)

- Nucleons are composite objects with inner structure. At low Q, perturbative QCD does not work well (expansion of coupling constant α_s)

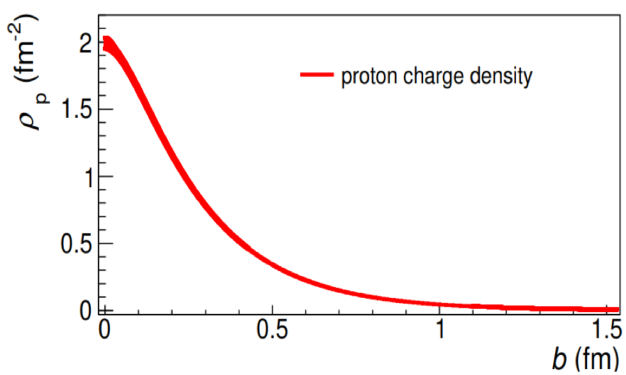
  ⇒ **Nucleon structure must be measured in experiments!**

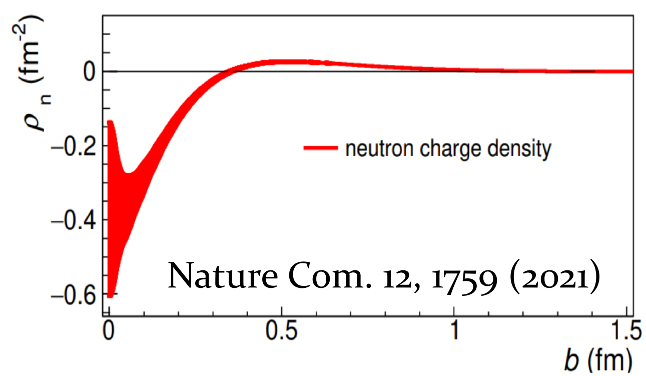






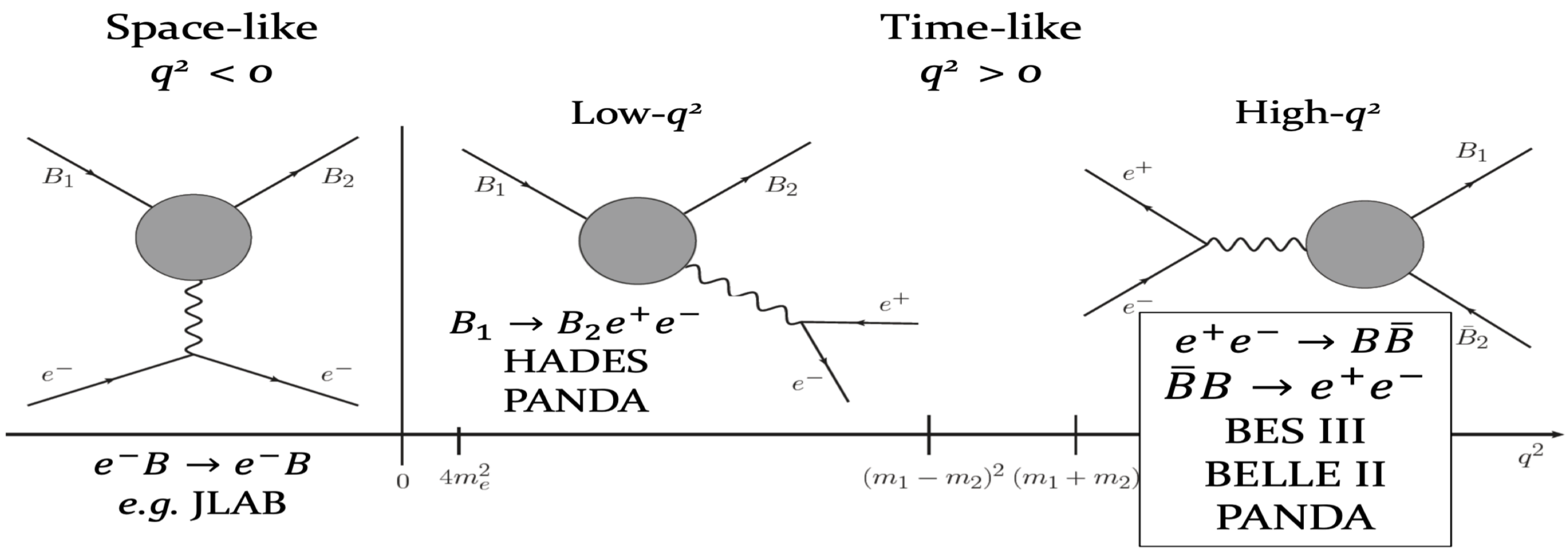
- Using photon as a probe, the coupling to nucleon can be expressed in terms EMFFs





Electromagnetic form factors

- **Fundamental properties of the nucleon**
  - Connected to charge, magnetization distribution
  - Crucial testing ground for models of the nucleon internal structure



The nucleon electromagnetic vertex Γ_μ describing the hadron current:

$$\Gamma_\mu(p', p) = \gamma_\mu F_1(q^2) + \frac{i\sigma_{\mu\nu}q^\nu}{2m_p} F_2(q^2)$$

Sachs FFs: $G_E(q^2) = F_1(q^2) + \tau\kappa_p F_2(q^2)$, $G_M(q^2) = F_1(q^2) + \kappa_p F_2(q^2)$

Normalization of FF: $q^2 = 0$: $G_E = F_1(0)$, $G_M = \mu_N$ $\quad q^2 = 4m_N^2$: $G_E = G_M$

Pair production of baryon

EMFFs parameterize the pair production cross section in e^+e^-

$$\frac{d\sigma_{B\bar{B}}(s)}{d\Omega} = \frac{\alpha^2\beta C}{4s}\left[|G_M(s)|^2(1+\cos^2\theta) + \frac{4m_B^2}{s}|G_E(s)|^2\sin^2\theta\right] \equiv N_0(1+\alpha_B\sin^2\theta)$$

Ratio $R_{em} = |G_E/G_M|$ reflects polar angle distribution of produced baryon!

$|G_E|$ and $|G_M|$ can be separately evaluated after determining N_0 and α_B.

After the integration over the polar angle θ

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

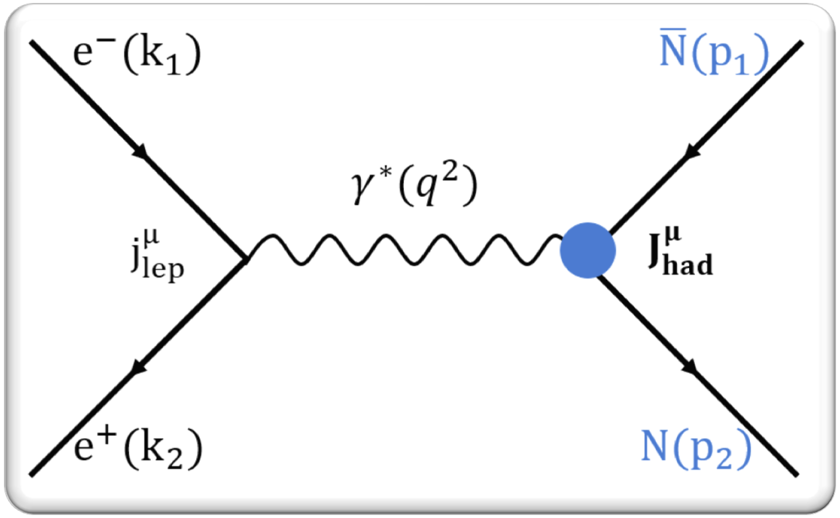
The so-called effective form factor could be defined in terms of EMFFs:

$$|G_{\mathrm{eff}}(s)| = \sqrt{\frac{\sigma_{B\bar{B}}(s)}{\frac{4\pi\alpha^2\beta C}{3s}\left(1+\frac{2m_B^2}{s}\right)}} = \sqrt{\frac{|G_M(s)|^2 + \frac{2m_B^2}{s}|G_E(s)|^2}{1+\frac{2m_B^2}{s}}}$$

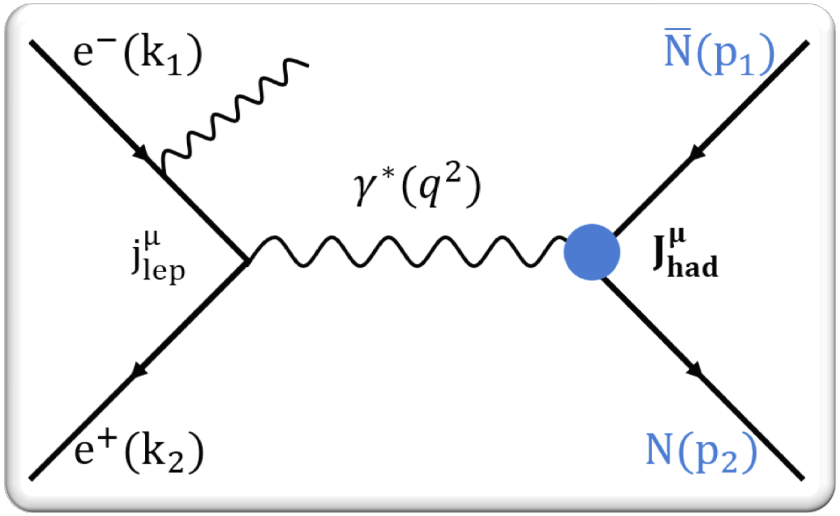
Effective FF reflects the magnitude of production cross section of baryon!

Experimental access of Time-like form factors

Energy scan



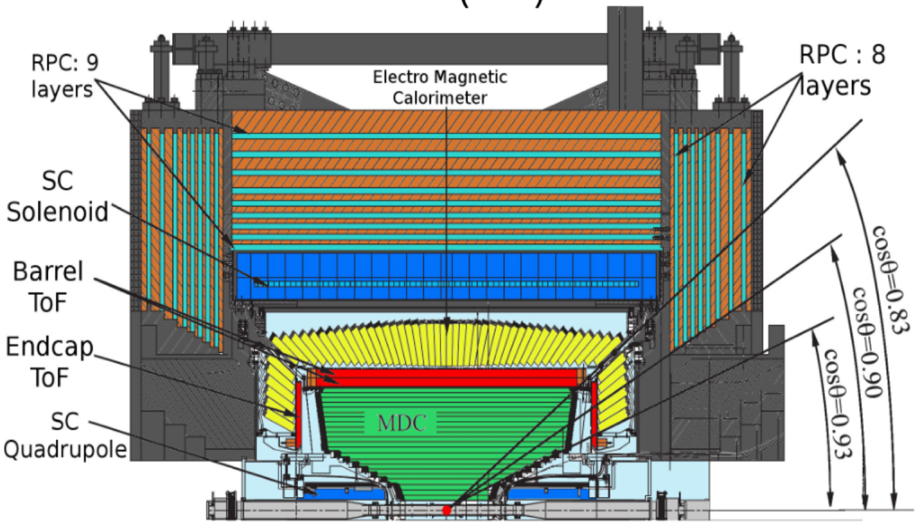
Initial-state-radiation



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

BEPCII and BESIII

NIM A614 (2010) 345



Superconducting Solenoid:
- 1T magnetic field

Time-of-Flight System:
- 90 – 110 ps resolution

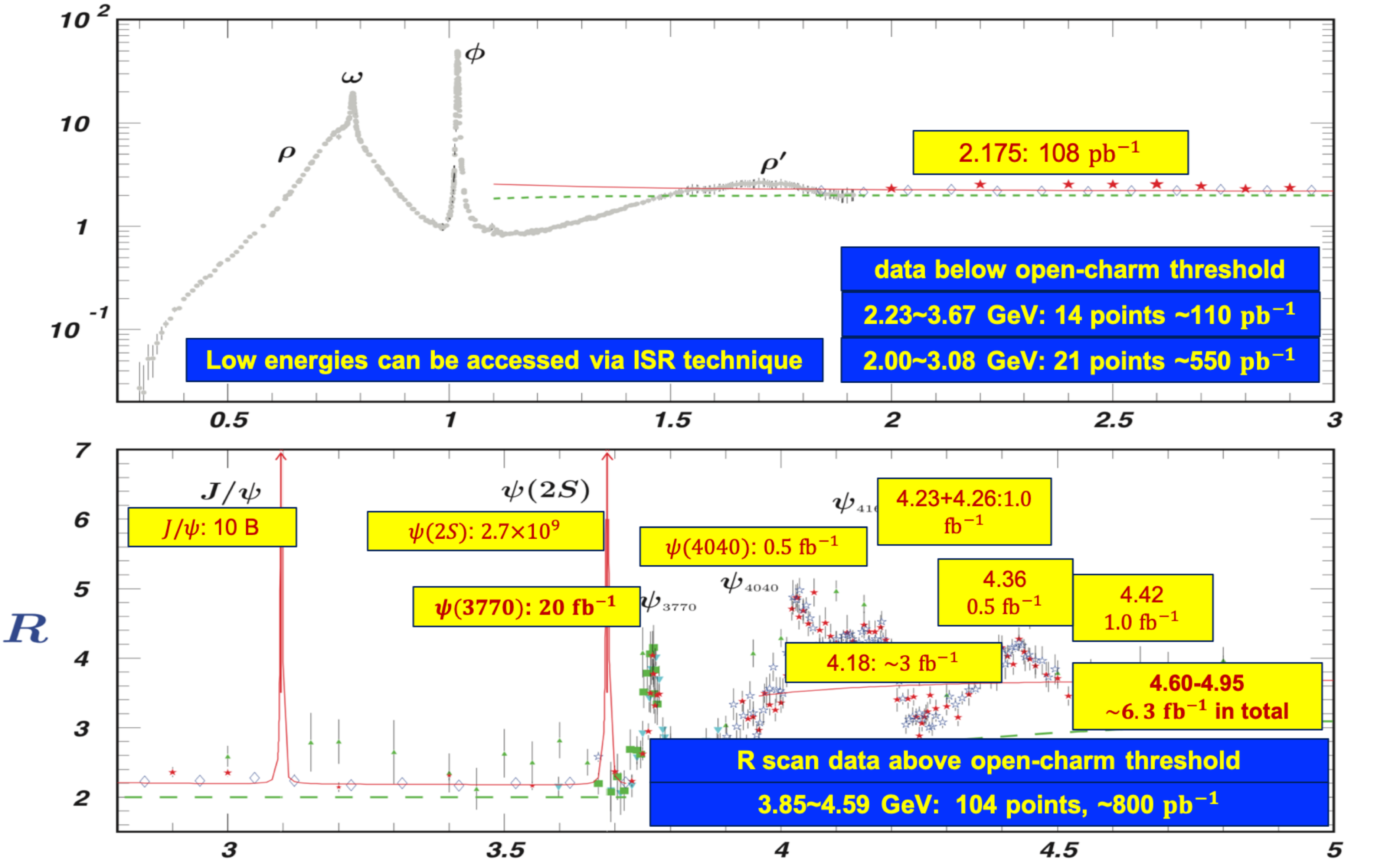
Drift Chamber:
- 0.5% momentum resolution
- 6% dE/dx resolution

Muon Chambers:
- 8-9 layers of RPCs
- 1.4-1.7 cm resolution
- P > 400 MeV

Electromagnetic Calorimeter:
- 6240 CsI(Tl) crystals
- 2.5% energy resolution
- 0.5 – 0.7 cm spatial resolution

- Located at the BEPCII collider (Beijing/China)
- Symmetric beams (2-5 GeV C.M. Energy)
- Maximum Luminosity: 1 nb^{-1}/s
- 93% coverage of the solid angle

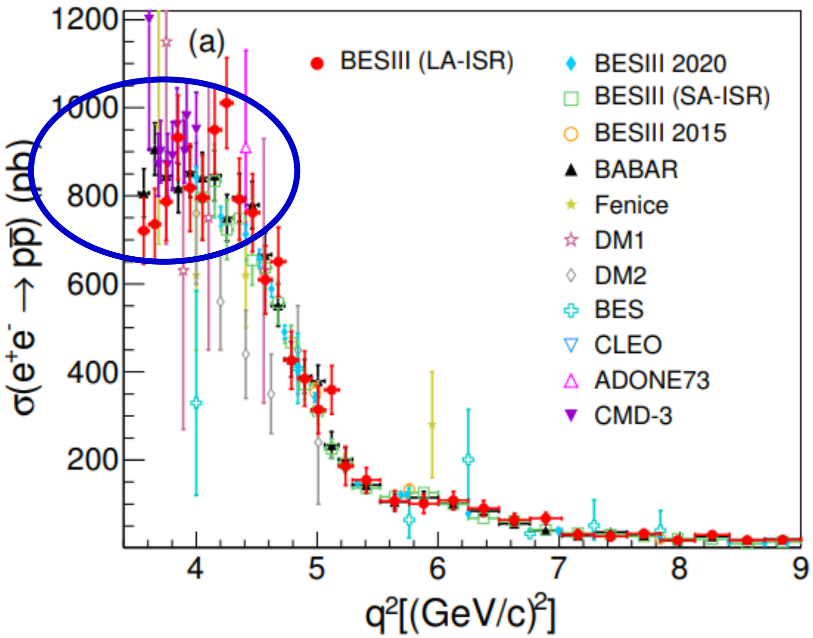
Data collected at BESIII

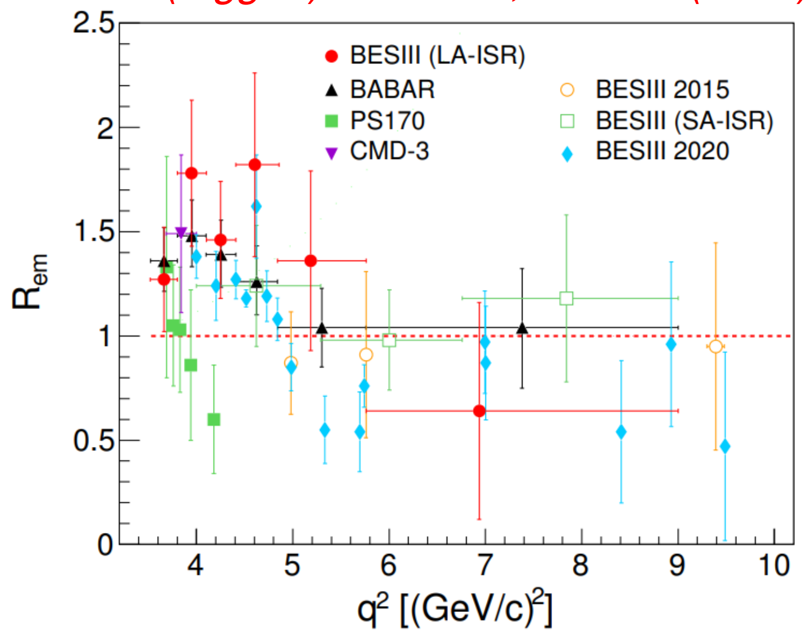


Proton form factors

ISR approach with detected and undetected ISR photon using BESIII data corresponds to 7.5 fb^{-1} integrated luminosity.

SA-ISR(un-tagged): PRD 99, 092002 (2019)
LA-ISR(tagged): PLB 817, 136328 (2019)



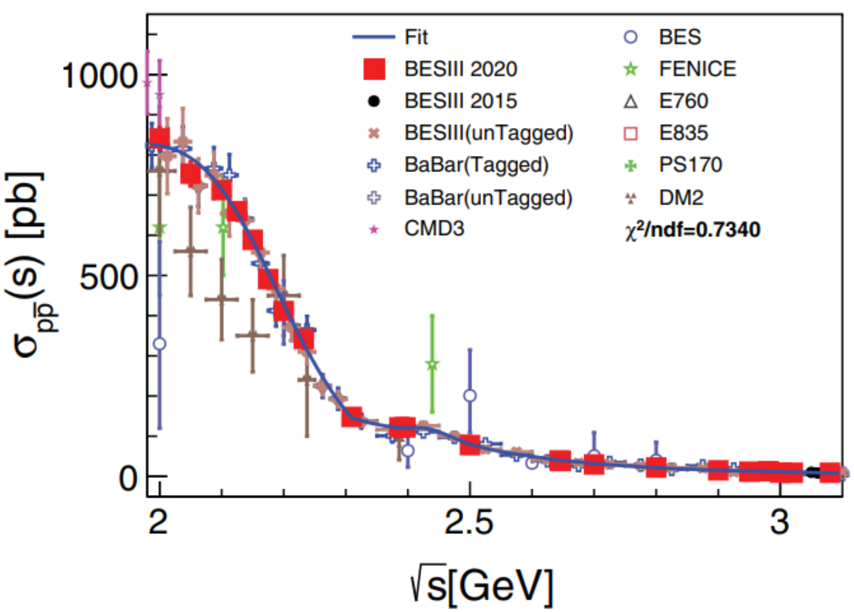


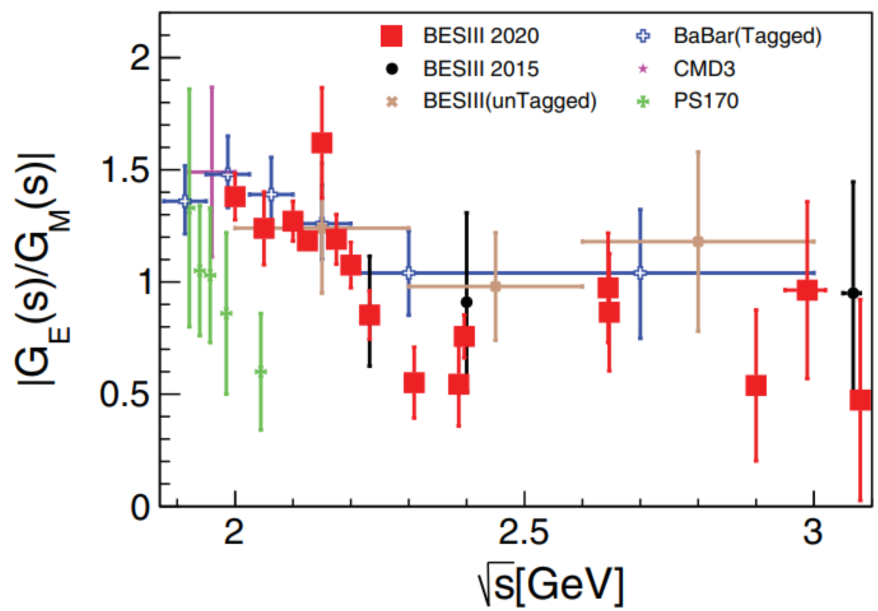
- From threshold to $q^2 = 4.0\ \mathrm{GeV}^2$, average cross section 840 pb
- Point-like cross section at threshold, $\sigma_{\text{point}} = \frac{\pi\alpha^2}{3m_B^2\tau}\left[1+\frac{1}{2\tau}\right] = 845\ \text{pb}$

Proton form factors

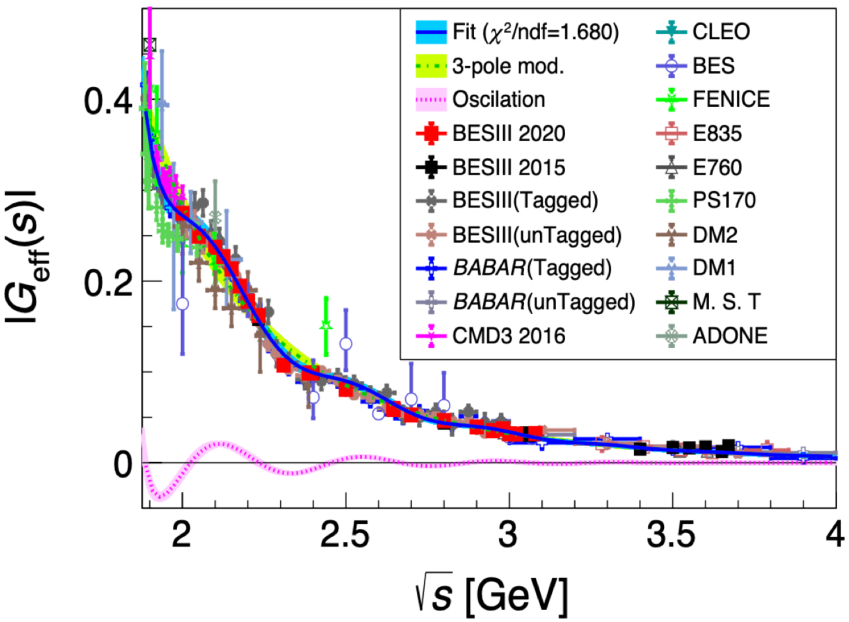
- Scan technique from 2.00 to 3.08 GeV at BESIII, using data of 688.5 pb^{-1}
- $|G_E/G_M|$ is determined with **high accuracy**, comparable with space-like region.
- $|G_E|$ and $|G_M|$ are separated by analyzing the polar angle distribution.

PRL 124, 042001 (2020)
PRD 91, 112004 (2015)

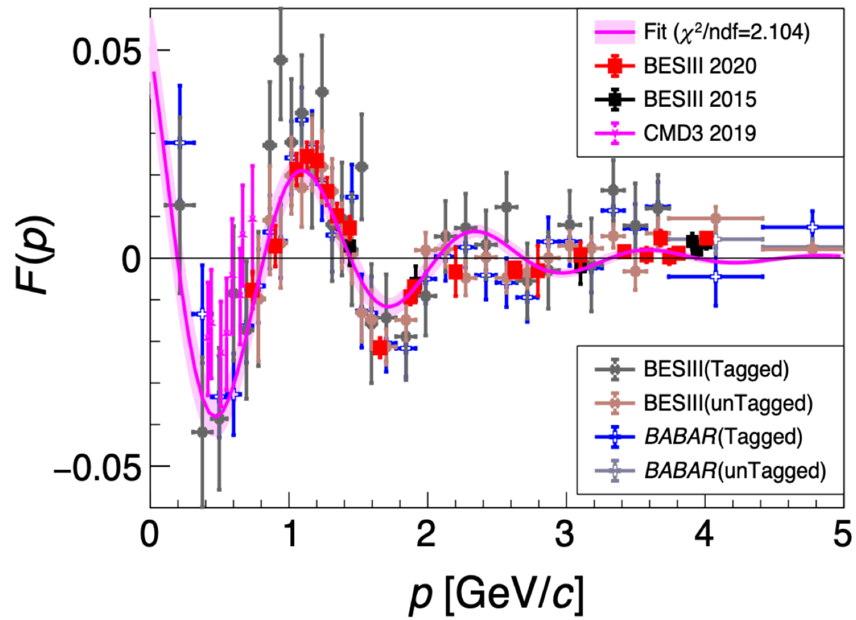




Oscillation feature confirmed in $|G_{\rm eff}|$



Lei Xia *et al*, *Symmetry* **2022**, *14*, 231

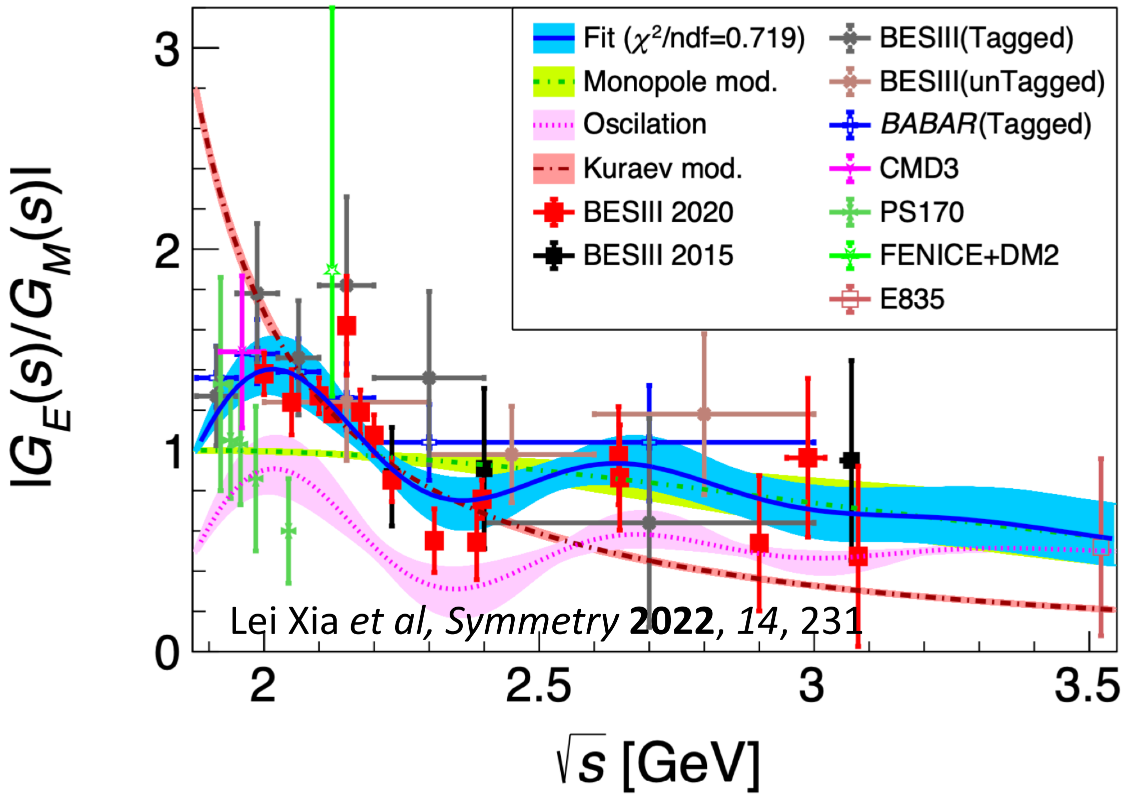


$|G_{\rm eff}|$ data are fitted with the model: the monopole decrease with a damped oscillation : *E. Tomasi-Gustafsson et al., PRL. 114, 232301 (2015), PRC 103, 035203 (2021)*

$$|G_{\rm eff}|(s) = \frac{\mathcal{A}}{\left(1+\frac{s}{a_0}\right)\left(1-\frac{s}{0.71\ \mathrm{GeV}^2}\right)^2} + b_0 e^{-b_1 p(s)} \cos[b_2 p(s) + b_3]$$

Oscillation feature in the cross section line-shape!

Oscillation feature in $|G_E/G_M|$



$|G_E/G_M|$ data can be well described by a function combining the monopole decrease with a damped oscillation

oscillation feature in the polar angle distribution of the outgoing proton!

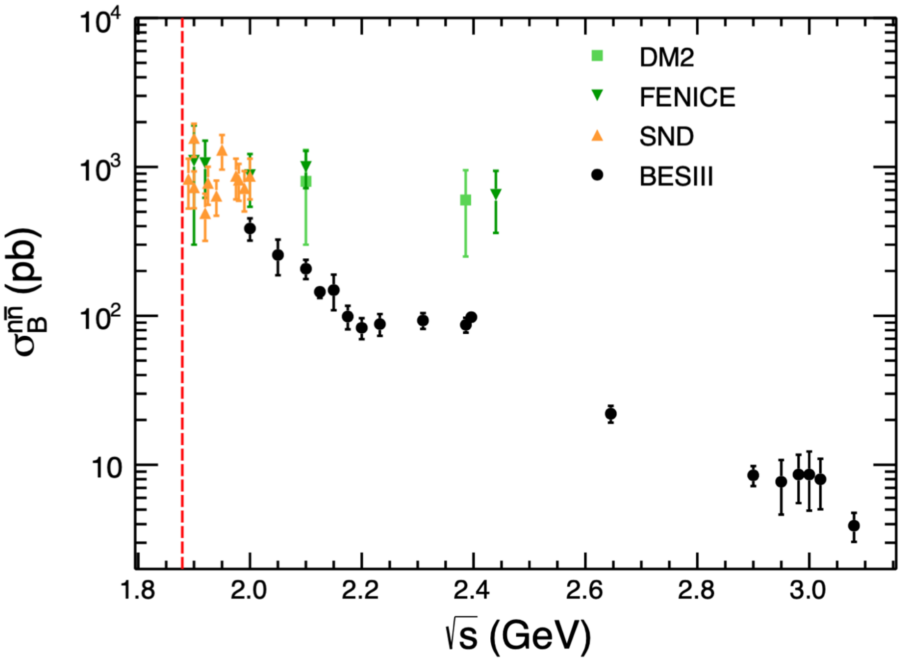
$|G_E/G_M|$ data are fitted with the model:

$$|G_E/G_M|(s) = \frac{1}{1+\omega^2(s)/r_0}\left[1 + r_1 e^{-r_2\omega(s)}\sin(r_3\omega(s))\right]$$

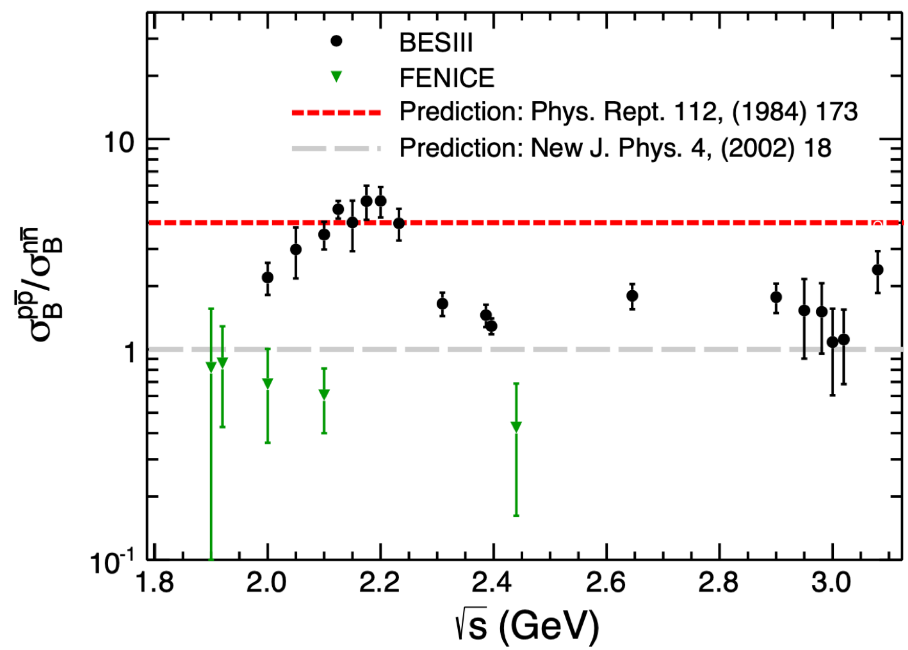
E. Tomasi-Gustafsson et al., PRL. 114, 232301 (2015), PRC 103, 035203 (2021)

Neutron form factors

- Scan technique from 2.00 to 3.08 GeV at BESIII, using data of $647.9\ \mathrm{pb}^{-1}$
- Unprecedented precision achieved, smaller than 8% at 2.396 GeV
- Clearly clarify the "puzzle" that photon-neutron coupling larger than photon-proton coupling which exists over 20 years.

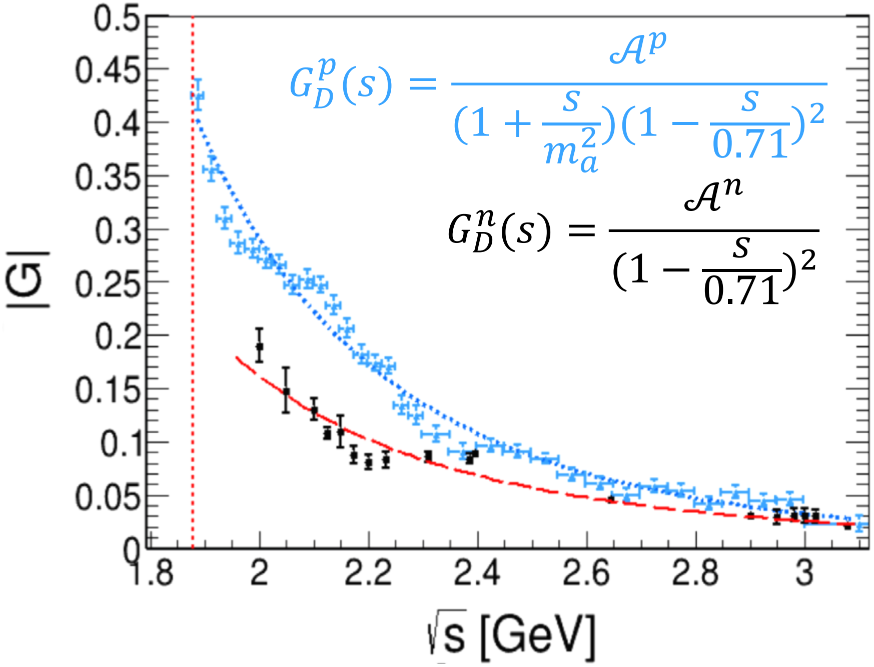


Nature Phys. 17 (2021) 11, 1200-1204

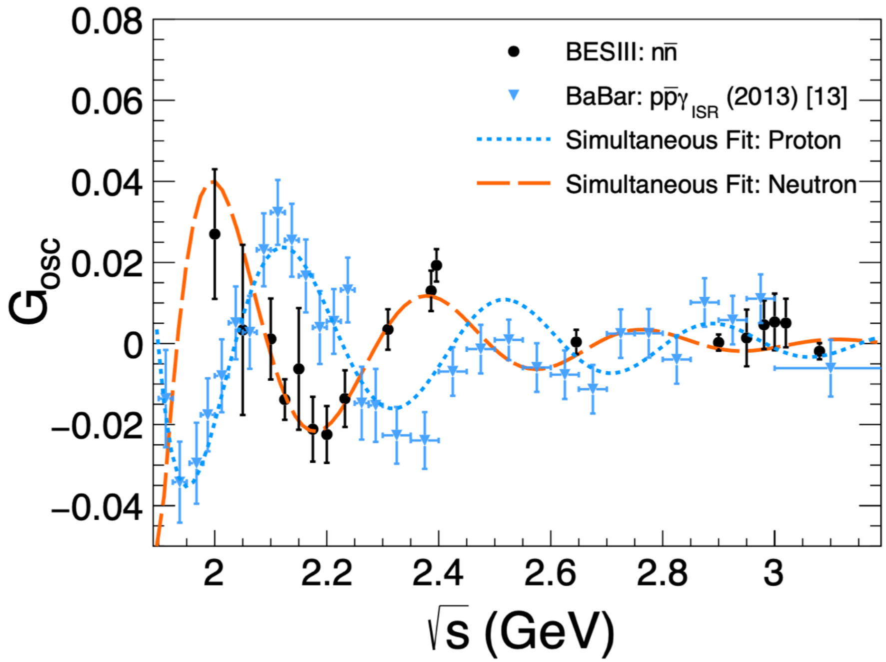


Oscillation feature in $|G_{\text{eff}}|$

- Oscillation in addition to the dipole law: $|G^{p,n}_{\text{eff}}(s)| = G^{p,n}_{D}(s) + G^{p,n}_{\text{osc}}(s)$
- Simultaneous fit on proton and neutron data with the same frequency but different phase: $G^{p,n}_{\text{osc}}(s) = b^{p,n}_0 e^{-b^{p,n}_1 p(s)} \cos[\boldsymbol{b_2} p(s) + b^{p,n}_3]$
- Fitted well but a phase shift around $(125 \pm 12)^\circ$ is observed



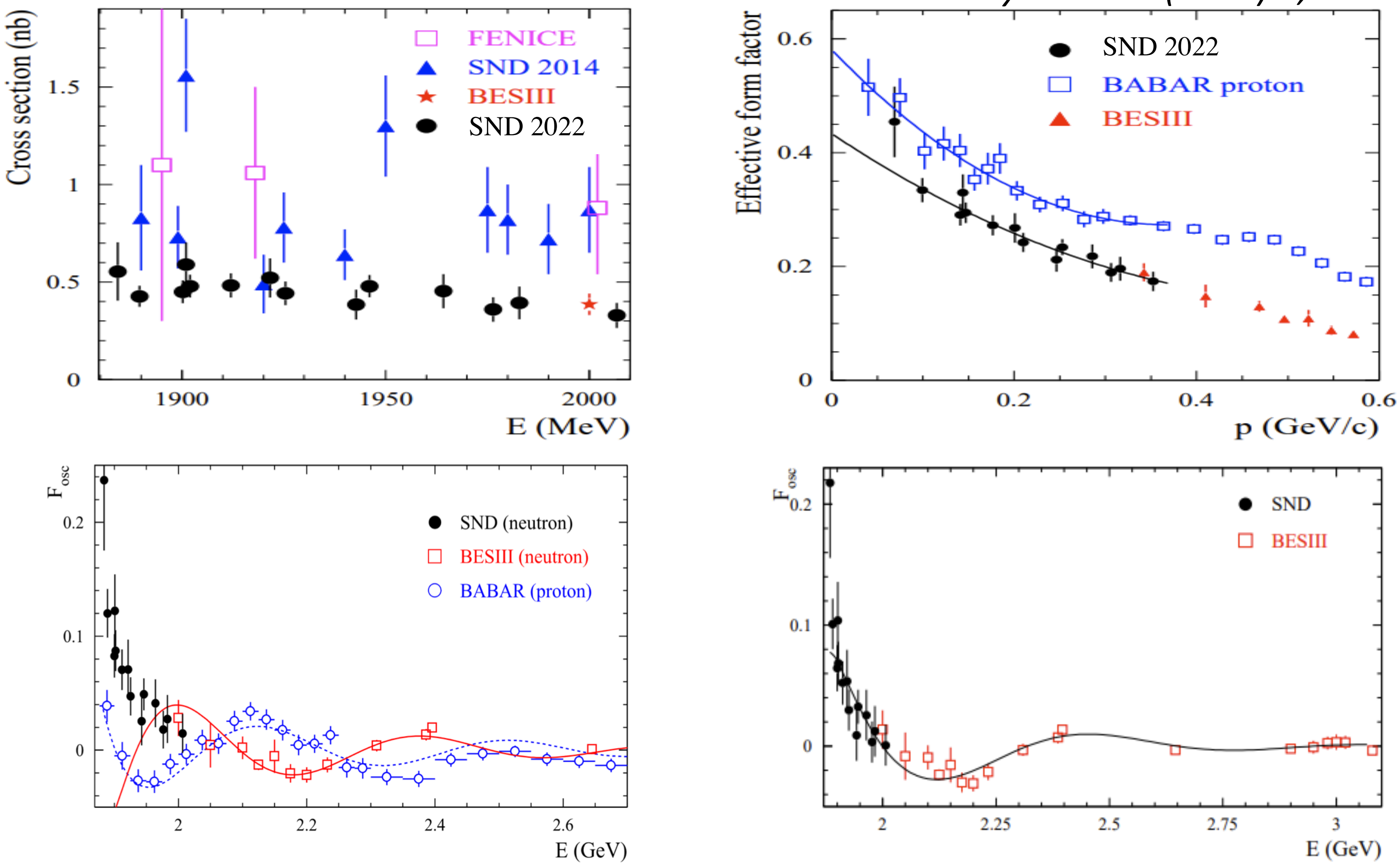
Nature Phys. 17 (2021) 11, 1200-1204



Oscillation feature in $|G_{\text{eff}}|$

Recent SND measurement suggests a different frequency:

Eur. Phys. J. C 82 (2022) 8, 761

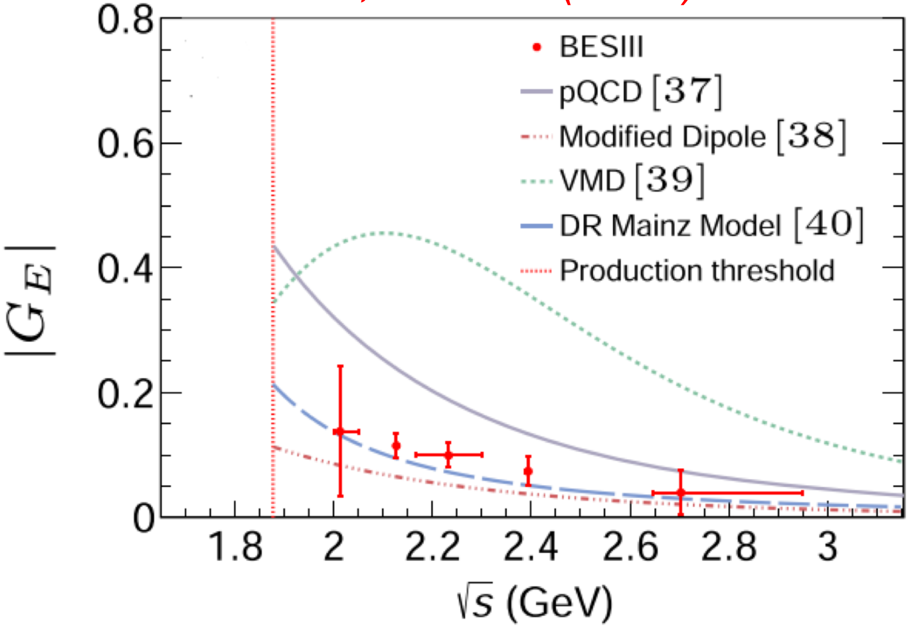


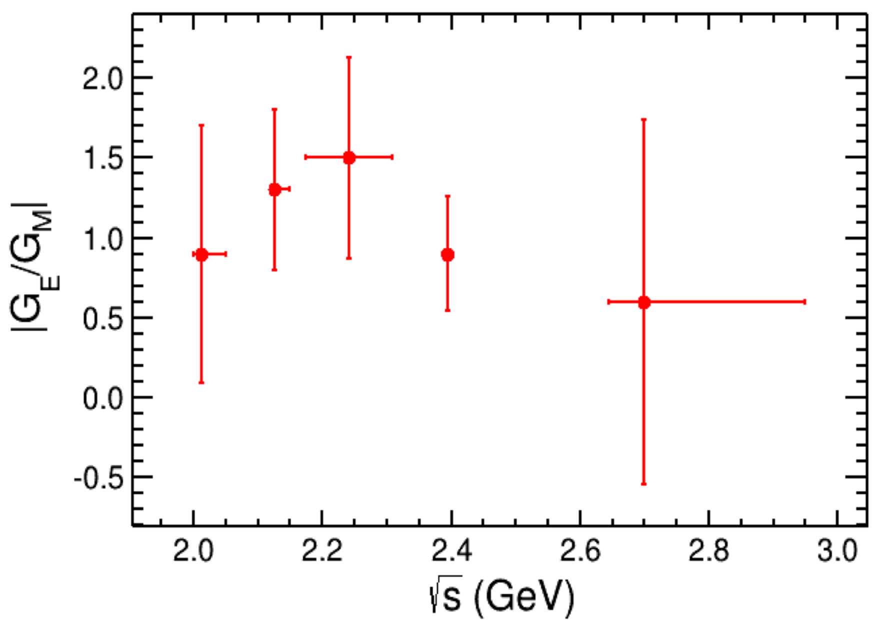
Additional experimental and theoretical inputs are desired!

$|G_E|$ and $|G_M|$ of neutron

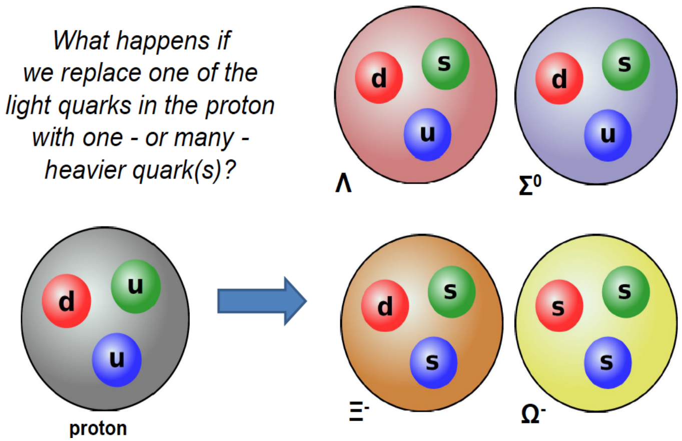
- $|G_E|$ and $|G_M|$ are obtained in 5 energy intervals due to the limited statistics, $|G_E/G_M|$ distribution is not shown in the paper
- BESIII $|G_M|$ values are smaller than that of FENICE by a factor of 2-3
- Data is compared with various models: pQCD, modified dipole, VMD and dispersion relations (DR), where the DR model gives good consistency

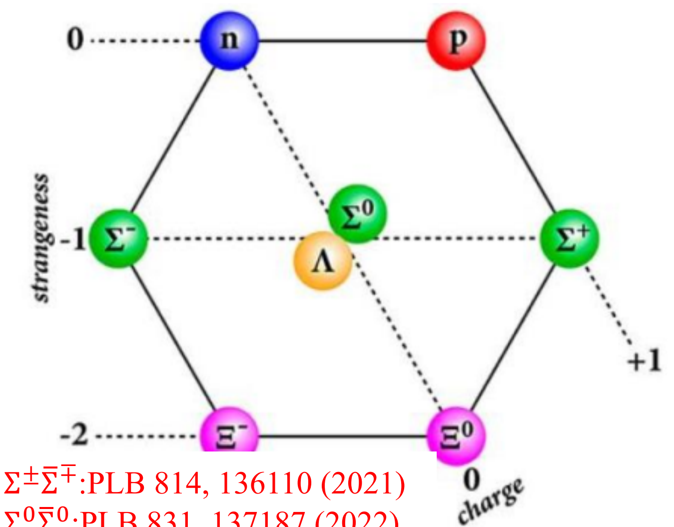
PRL 130, 151905 (2023)





Production cross section of hyperons

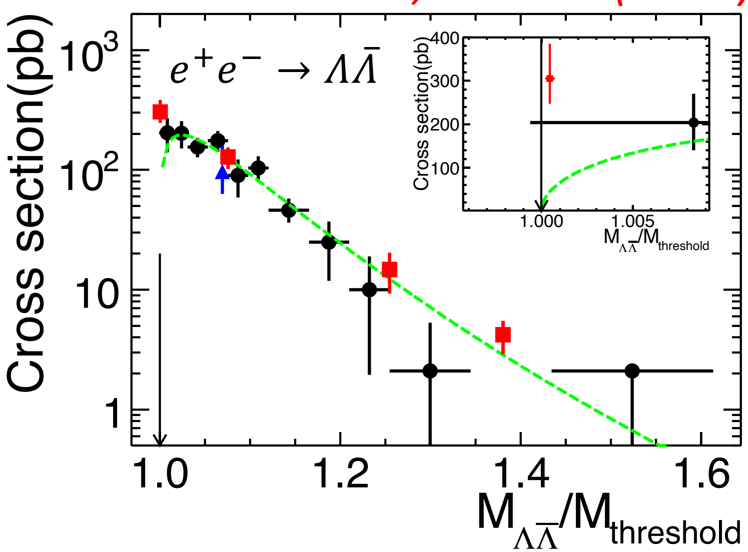


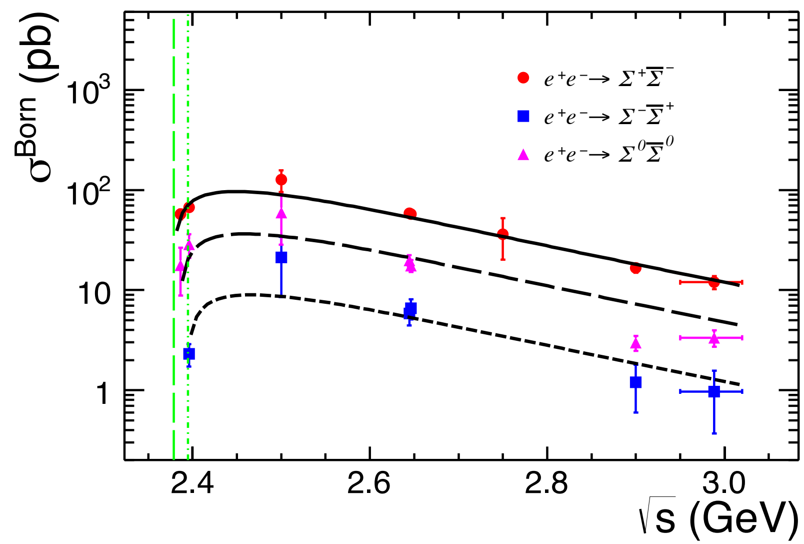


$\Sigma^{\pm}\bar{\Sigma}^{\mp}$:PLB 814, 136110 (2021)

$\Sigma^{0}\bar{\Sigma}^{0}$:PLB 831, 137187 (2022)

PRD 97, 032013 (2018)



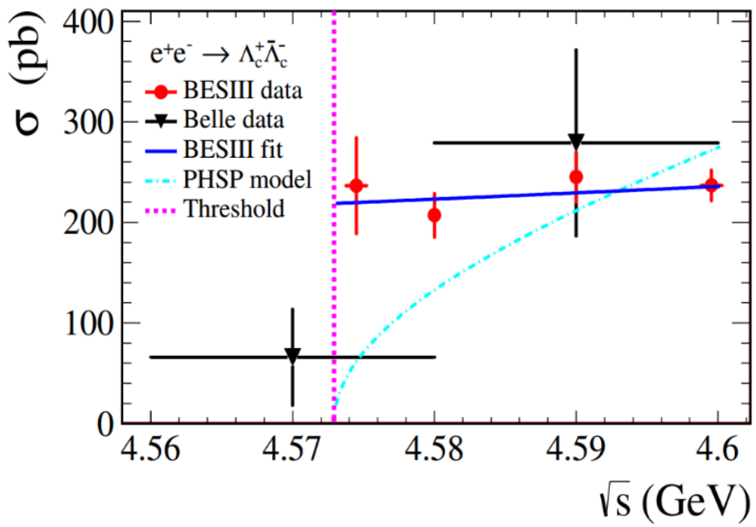


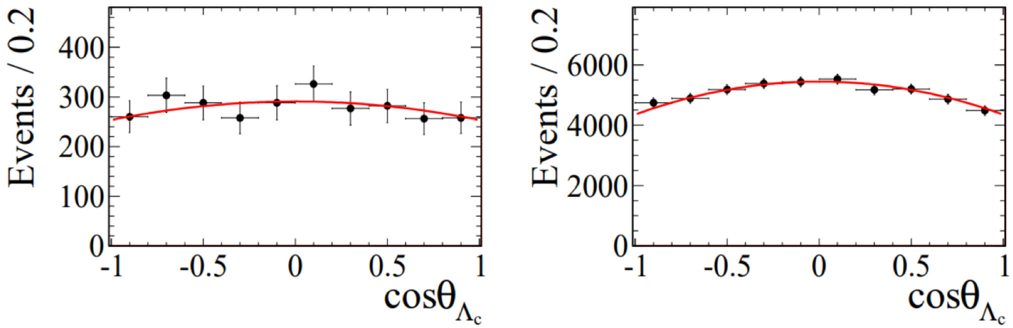
EMFF data of hyperon is limited due to the small statistics

Production of charmed hyperon

BESIII measured the production of Λ_c **near-threshold**:

PRL 120, 132001 (2018)





$\sqrt{s}$ (MeV)	α_{Λ_c}	$\lvert G_E/G_M \rvert$
4574.5	$-0.13 \pm 0.12 \pm 0.08$	$1.14 \pm 0.14 \pm 0.07$
4599.5	$-0.20 \pm 0.04 \pm 0.02$	$1.23 \pm 0.05 \pm 0.03$

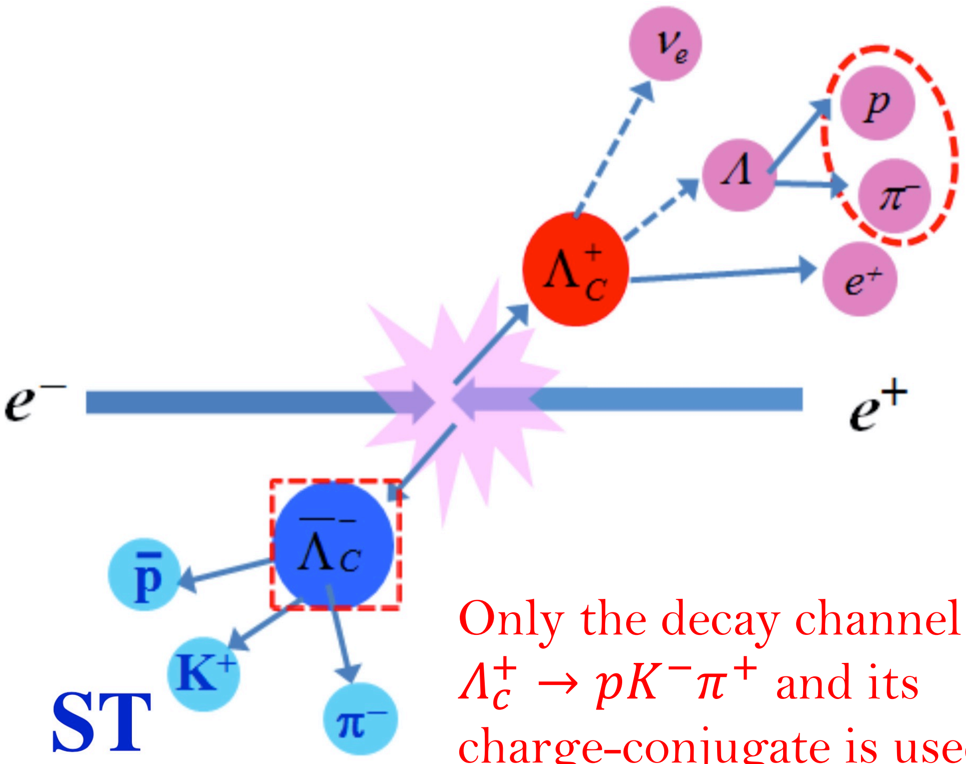
- Precise non-zero cross section near the kinematic threshold, a significantly different energy-dependent trend from Belle's measurement
- $|G_E/G_M|$ is consistent with 1 near the kinematic threshold
- Results are limited in a narrow c.m. energy region near threshold

A thorough study of the cross section and EMFFs is needed!

Cross section and EMFF measurements of Λ_c^+

A combined approach of the single tag (ST) and double tag (DT):

$\sqrt{s}$ (GeV)	$\mathcal{L}_{\rm int}$ (pb^{-1})
4.6119	103.83
4.6280	521.52
4.6409	552.41
4.6612	529.63
4.6819	1669.31
4.6988	536.45
4.7397	164.27
4.7500	367.21
4.7805	512.78
4.8431	527.29
4.9180	208.11
4.9509	160.37

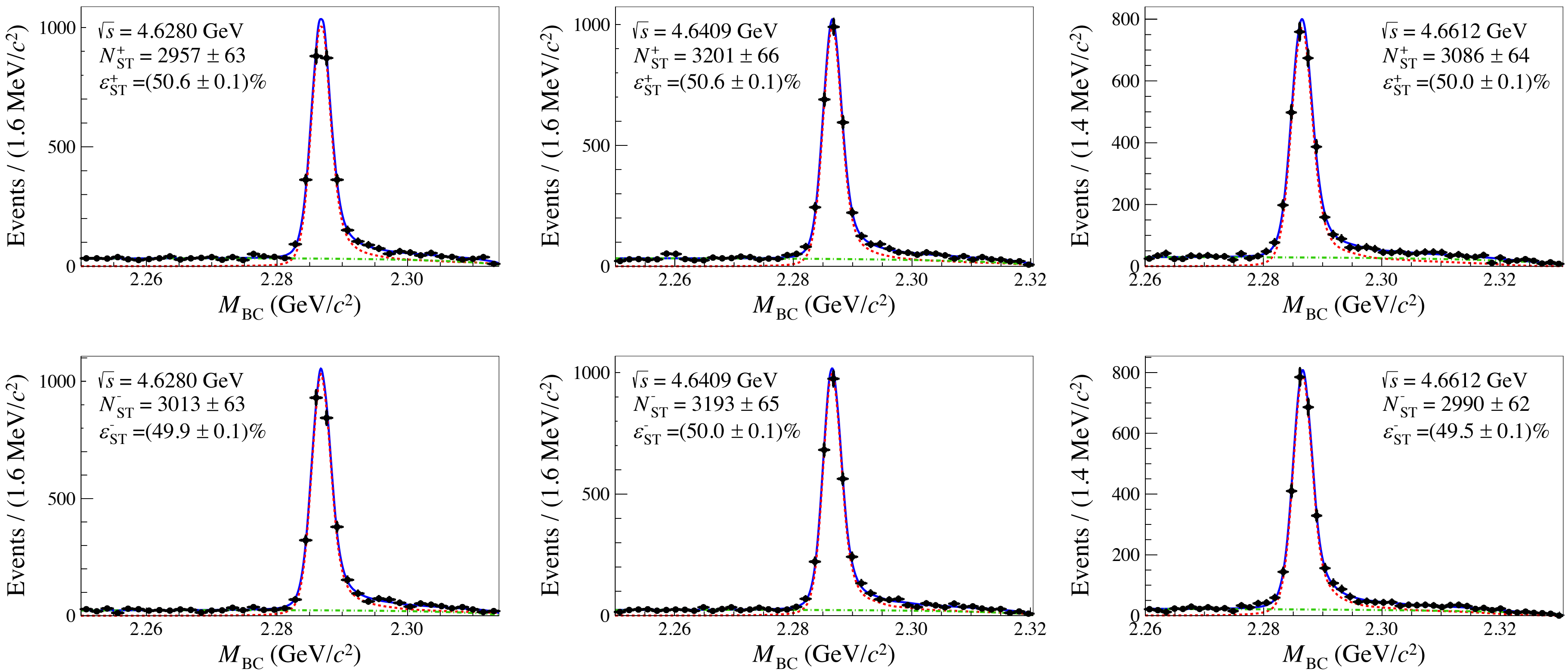


Only the decay channel $\Lambda_c^+ \to pK^-\pi^+$ and its charge-conjugate is used

Sufficient statistics enable a DT analysis to reduce uncertainty!

Production cross section of Λ_c^+

Significant positive and negative ST yields in the Y(4630) region:



Flat energy-dependent L_{int}, ST yields, and efficiency results in flat cross section

Production cross section of Λ_c^+

The Born cross section of channel $\Lambda_c^+ \to pK^-\pi^+$ and $\bar{\Lambda}_c^- \to \bar{p}K^+\pi^-$:

$$\sigma_\pm = \frac{N_{\mathrm{ST}}^\pm}{\varepsilon_{\mathrm{ST}}^\pm \mathcal{L}_{\mathrm{int}} f_{\mathrm{VP}} f_{\mathrm{ISR}} \mathcal{B}_\pm}$$

$$N_{\mathrm{ST}}^{\pm,n} = N_{\Lambda_c^+\bar{\Lambda}_c^-}^n \varepsilon_{\mathrm{ST}}^{\pm,n} \mathcal{B}_\pm, \quad N_{\mathrm{DT}}^n = N_{\Lambda_c^+\bar{\Lambda}_c^-}^n \mathcal{B}_+\mathcal{B}_-\varepsilon_{\mathrm{DT}}^n$$

Thus,

$$N_{\mathrm{DT}}^n = \mathcal{B}_\pm \frac{N_{\mathrm{ST}}^{\mp,n}\varepsilon_{\mathrm{DT}}^n}{\varepsilon_{\mathrm{ST}}^{\mp,n}}, \quad N_{\mathrm{DT}} = \sum_{n=1}^{9} N_{\mathrm{DT}}^n = \mathcal{B}_\pm \sum_{n=1}^{9}\left(\frac{N_{\mathrm{ST}}^{\mp,n}\varepsilon_{\mathrm{DT}}^n}{\varepsilon_{\mathrm{ST}}^{\mp,n}}\right)$$

As a result

$$\mathcal{B}_\pm = N_{\mathrm{DT}} \Big/ \sum_{n=1}^{9}\left(\frac{N_{\mathrm{ST}}^{\mp,n}\varepsilon_{\mathrm{DT}}^n}{\varepsilon_{\mathrm{ST}}^{\mp,n}}\right)$$

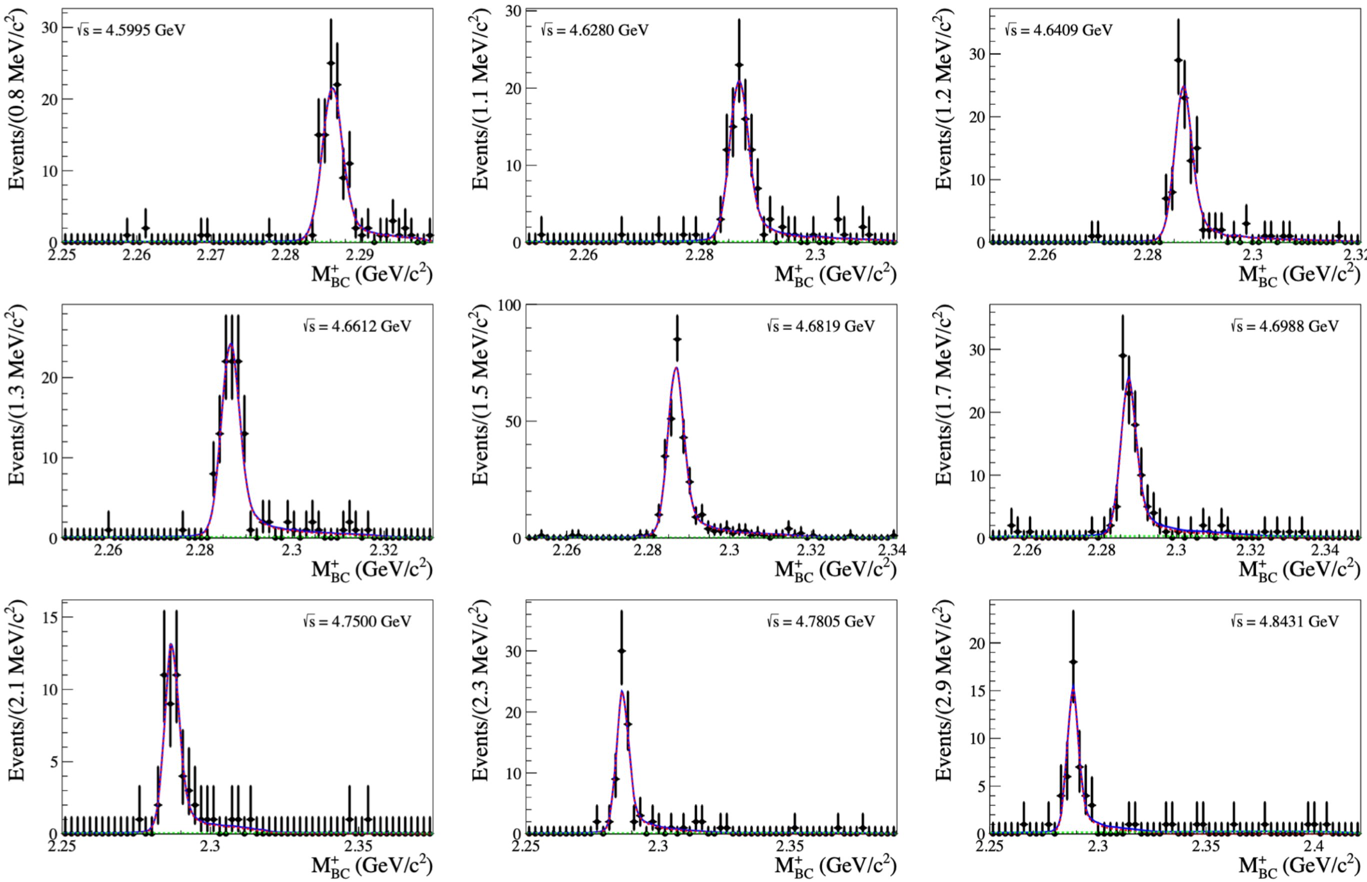
Thus,

$$\sigma_\pm = \frac{N_{\mathrm{ST}}^\pm}{\varepsilon_{\mathrm{ST}}^\pm \mathcal{L}_{\mathrm{int}} f_{\mathrm{VP}} f_{\mathrm{ISR}} N_{\mathrm{DT}}} \sum_{n=1}^{9}\left(\frac{N_{\mathrm{ST}}^{\mp,n}\varepsilon_{\mathrm{DT}}^n}{\varepsilon_{\mathrm{ST}}^{\mp,n}}\right)$$

- Most of the uncertainties in $\varepsilon_{\mathrm{ST}}^\pm$ (due to tracking and PID) are reduced.
- The double counting between the uncertainties of $\varepsilon_{\mathrm{ST}}^\pm$ and $\mathcal{B}_\pm$ is avoided.
- Data samples with $\mathcal{L}_{\mathrm{int}} > 350\ \mathrm{pb}^{-1}$ is used in the double tag analysis.

Production cross section of Λ_c^+

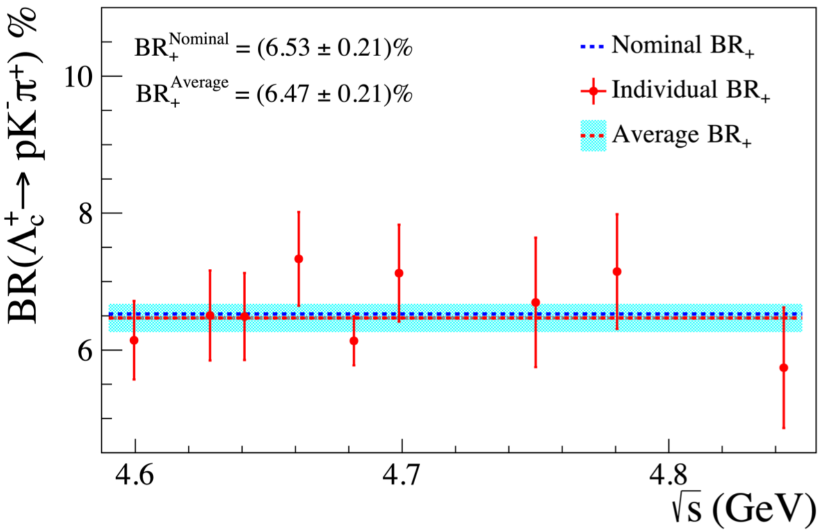
Branching fraction and DT yield is determined by a simultaneous fit:

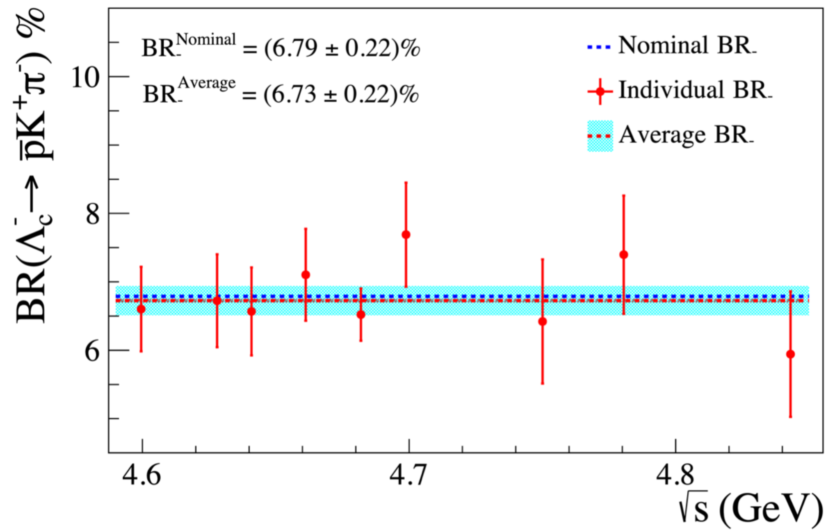


- A total of 9 data sets are used, small fraction of background events
- $\mathcal{B}_\pm$ is the shared parameter in the fit, and $\mathcal{B}_+$ and $\mathcal{B}_-$ are determined separately

Production cross section of Λ_c^+

To verify the obtained $\mathcal{B}_\pm$, its energy-dependency is checked:





$\mathcal{B}_+ = (6.53 \pm 0.21)\%$
$\mathcal{B}_- = (6.79 \pm 0.22)\%$
$\mathcal{B} = (6.66 \pm 0.22)\%$
$N_{DT} = 1007 \pm 32$

measurements	$\mathcal{B}(\%)$	Ref. and comments
Belle	$6.84 \pm 0.24^{+0.21}_{-0.27}$	[PRL 113 042002 (2014)]
BESIII 2016	$5.84 \pm 0.27 \pm 0.23$	[PRL 116 052001 (2016)]
PDG	6.26 ± 0.29	[PDG 2023]
BESIII 2023	6.66 ± 0.22	statistical error only

- Systematic uncertainty is reduced by a factor of 2, i.e., from 6.0% to 3.2%
- **Our branching fraction result is consistent with that of Belle!**

Production cross section of Λ_c^+

The Born cross section:

$$\sigma_{\pm} = \frac{N_{\rm ST}^{\pm}}{\varepsilon_{\rm ST}^{\pm}\mathcal{L}_{\rm int} f_{\rm VP} f_{\rm ISR} N_{\rm DT}} \sum_{n=1}^{9} \left(\frac{N_{\rm ST}^{\mp,n}\varepsilon_{\rm DT}^{n}}{\varepsilon_{\rm ST}^{\mp,n}} \right)$$

The average Born cross section:

$$\sigma = \sum_{i=\pm} \omega_i \sigma_i, \omega_i = (1/\Delta\sigma_i^2) \Big/ \left(\sum_i 1/\Delta\sigma_i^2 \right)$$

and corresponding uncertainty takes the form

$$\Delta\sigma^2 = \sum_{i,j=\pm} \omega_i (\mathbf{M}^{\sigma})_{ij} \omega_j, \mathbf{M}^{\sigma} = \mathbf{M}^{\sigma}_{\rm stat} + \mathbf{M}^{\sigma}_{\rm syst}$$

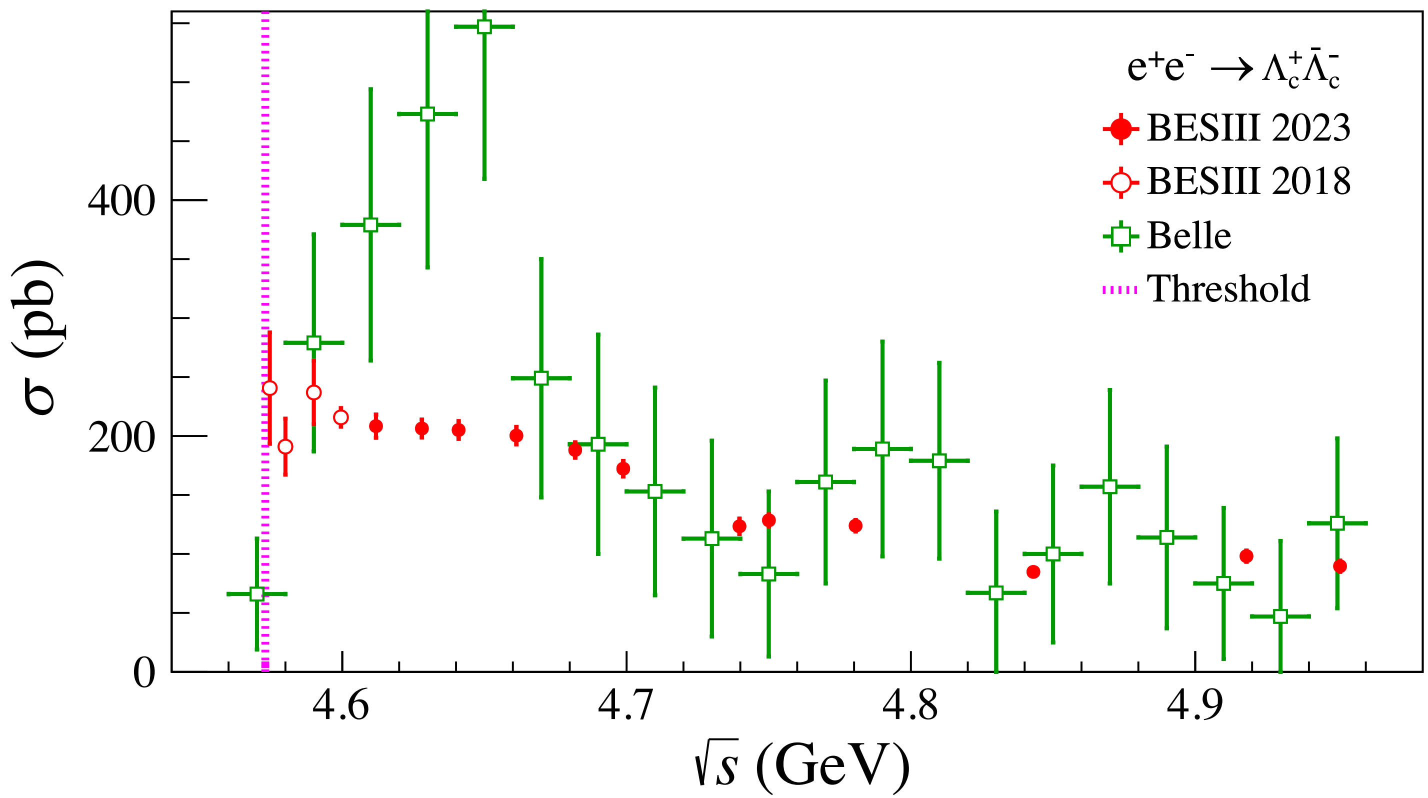
or approximately

$$\Delta\sigma^2_{\rm stat} = \sum_{i,j=\pm} \omega_i (\mathbf{M}^{\sigma}_{\rm stat})_{ij} \omega_j \quad \text{and} \quad \Delta\sigma^2_{\rm syst} = \sum_{i,j=\pm} \omega_i (\mathbf{M}^{\sigma}_{\rm syst})_{ij} \omega_j$$

The covariance matrix $\mathbf{M}^{\sigma}$ counts for independent and correlated uncertainties.

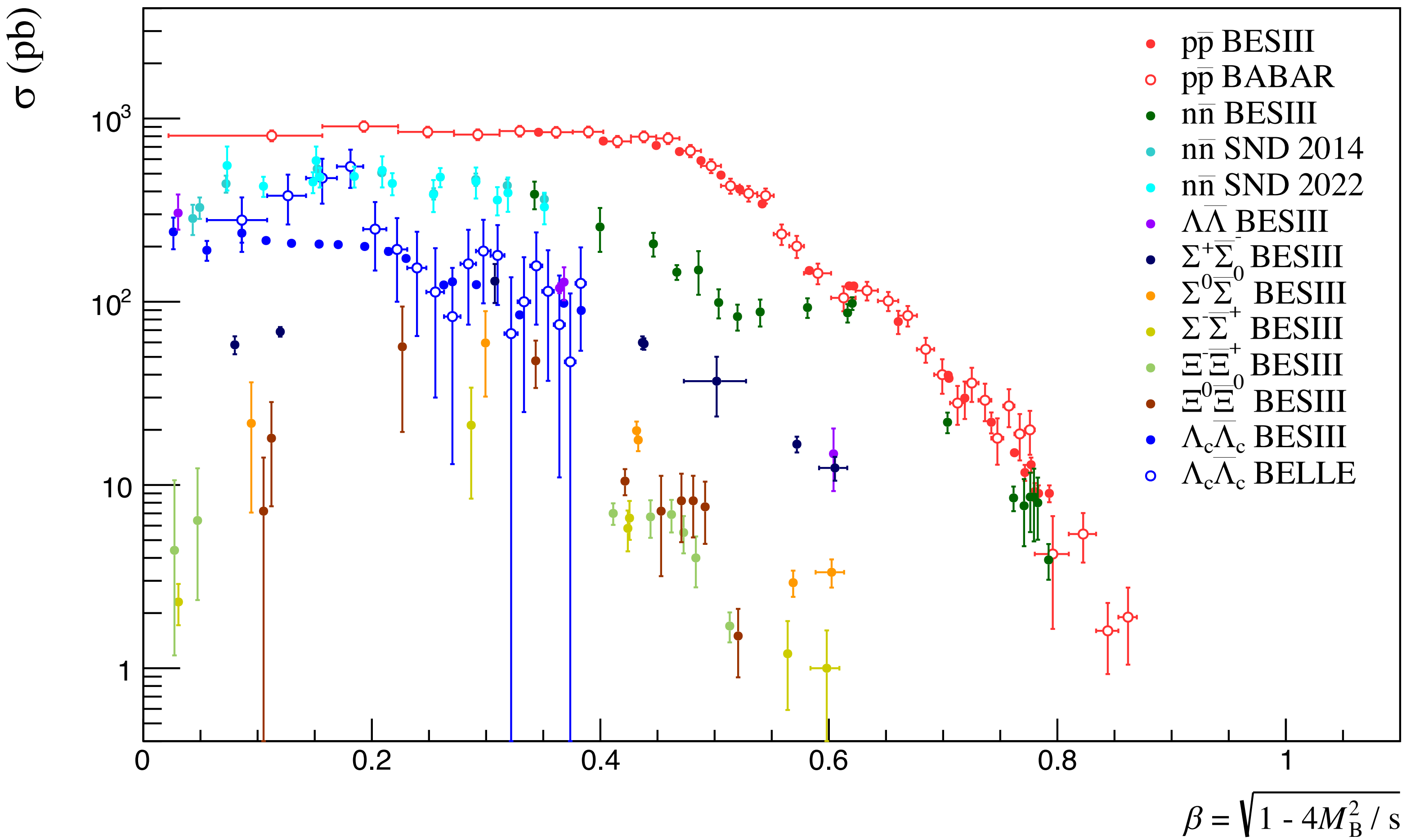
The $i = +, -$ indexed results of tagging $\Lambda_c^+ \to pK^-\pi^+$ and $\bar{\Lambda}_c^- \to \bar{p}K^+\pi^-$, respectively.

Production cross section of Λ_c^+



- Typical uncertainty is less than 4.0%, which is dominated by that of $\mathcal{B}_{\pm}$
- Cross sections at first four points are re-evaluated using updated $\mathcal{L}_{\text{int}}$ and $\mathcal{B}_{\pm}$
- Near-threshold cross-section plateau is confirmed up to 4.68 GeV, and no resonance structure is observed around 4.64 GeV -- **no charmed baryonium?**

Production cross section of Λ_c^+

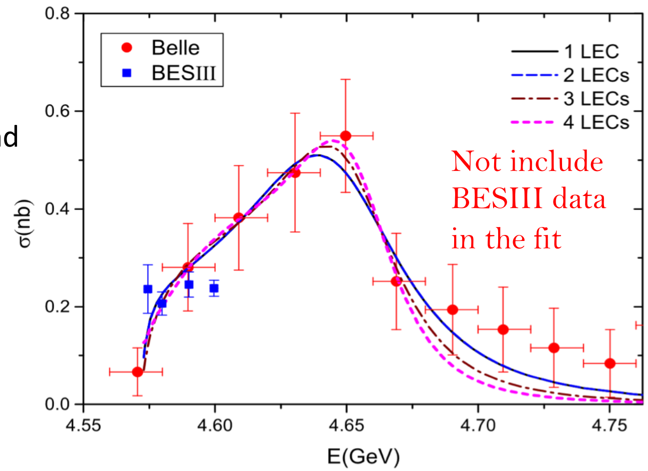


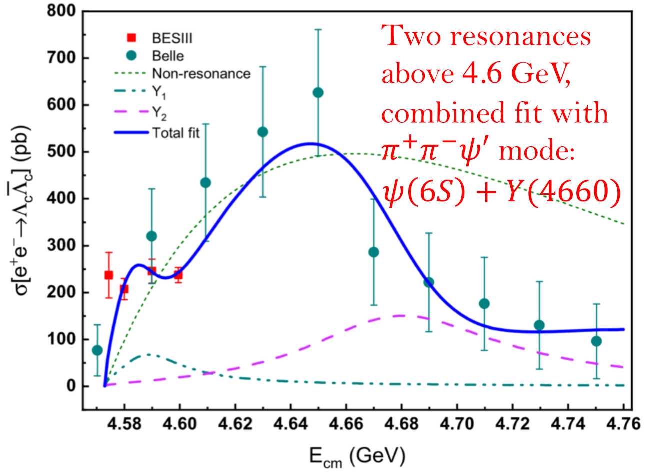
Similar momentum-dependency with the proton and neutron

Discussions in the theoretical point of view

BESIII data affects the parameterization of Y(4630):

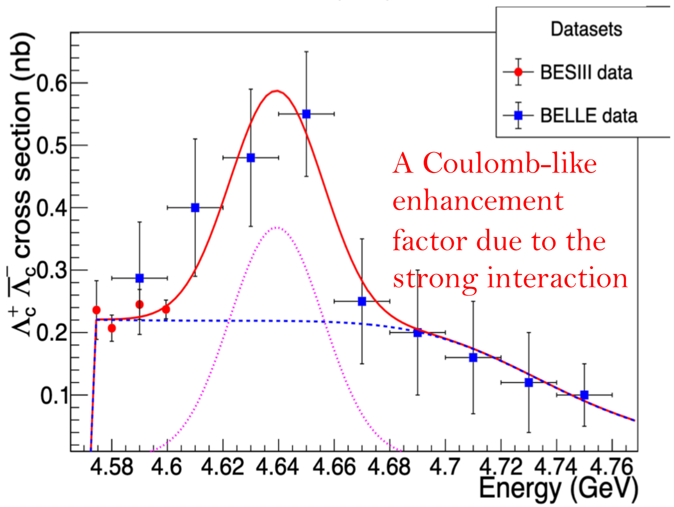
Ling-Yun Dai, Johann Haidenbauer, and Ulf-G. Meißner, PRD **96**, 116001 (2017)

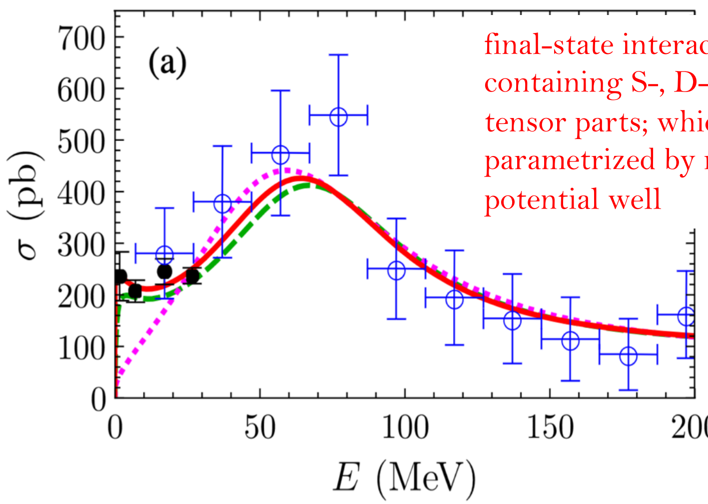




Jun-Zhang Wang, Ri-Qing Qian, Xiang Liu, and Takayuki Matsuki, PRD **101**, 034001 (2020)

A. Amoroso *et al*, *Universe* 2021, **7**, 436





final-state interaction containing S-, D-wave, and tensor parts; which are parametrized by rectangular potential well

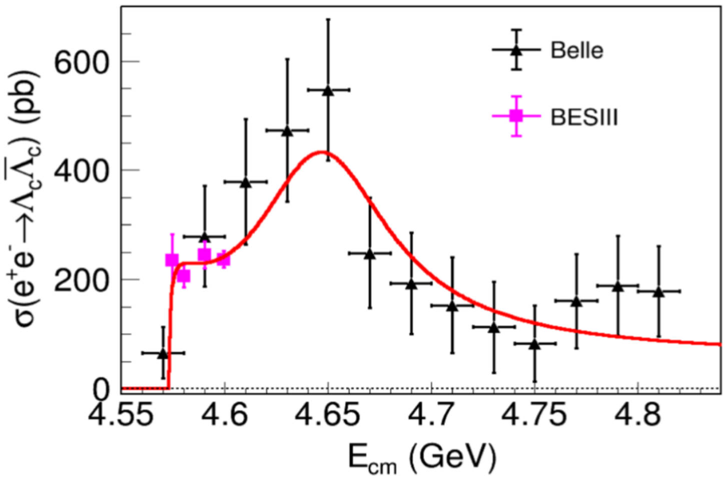
A. I. Milstein and S. G. Salnikov, PRD **105**, 074002 (2022)

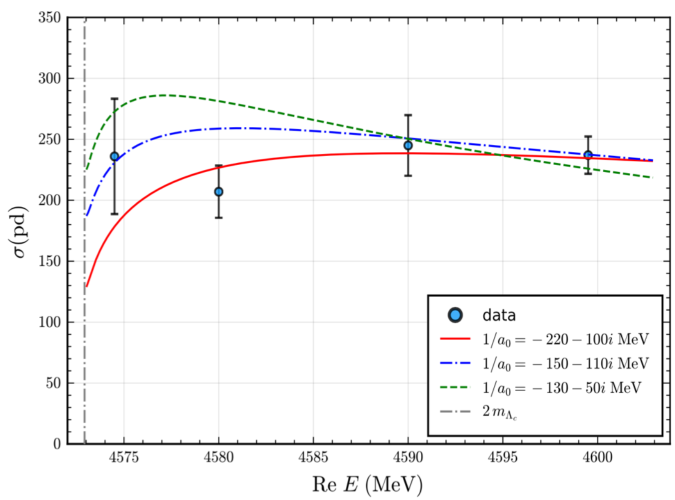
A plenty of theoretical models are triggered by BESIII data!

Discussions in the theoretical point of view

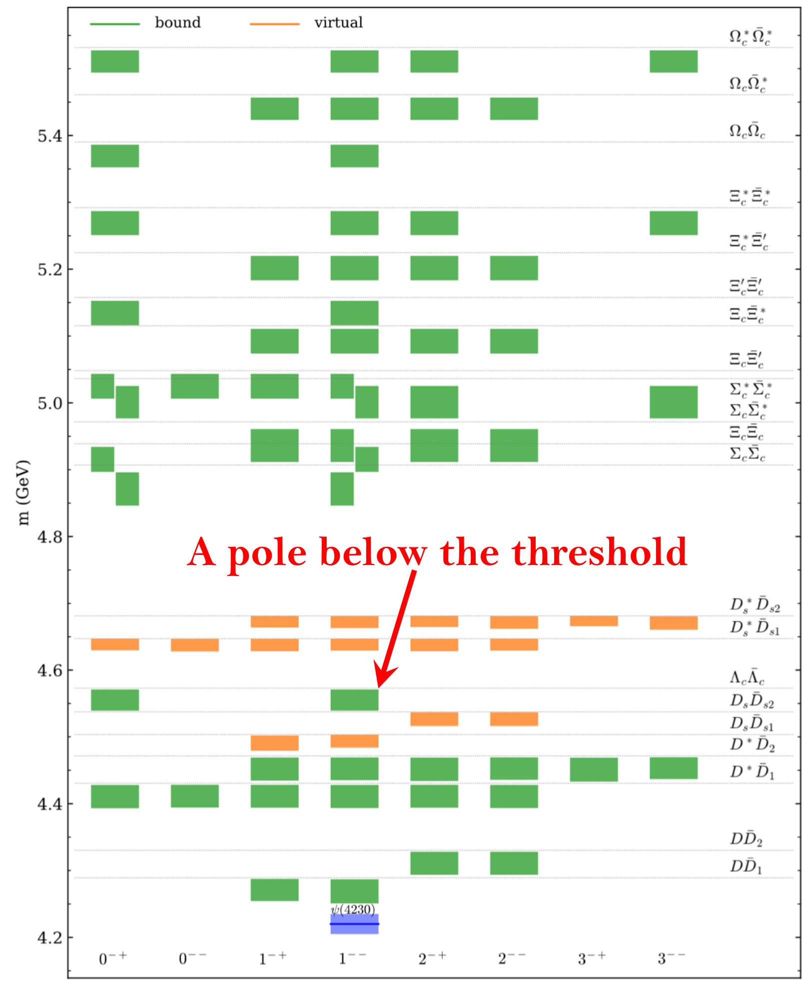
BESIII data affects the parameterization of Y(4630):

Qin-Fang Cao, Hong-Rong Qi, Yu-Fei Wang, and Han-Qing Zheng, PRD **100**, 054040 (2019)





Xiang-Kun Dong, Feng-Kun Guo, and Bing-Song Zou, *Progr. Phys.* **41** (2021) 65-93



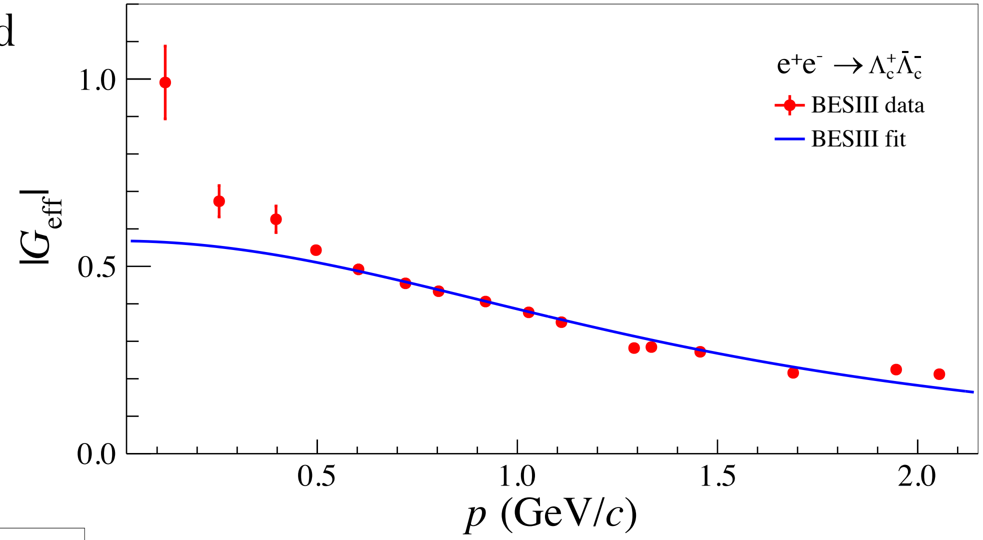
Effective form factor of Λ_c^+

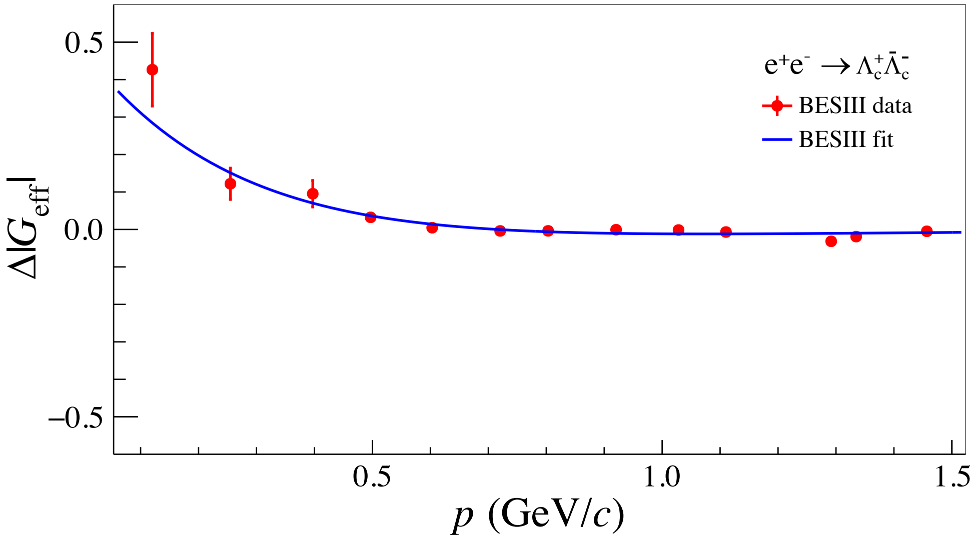
The effective form factors spectrum is fitted with a three-pole model:

$$G_{3p}(s) = \frac{g}{\left(1+\frac{s}{g_a}\right)\left(1-\frac{s}{g_b}\right)^2}$$

where

$$p = \sqrt{\left(\frac{s}{2m_{\Lambda_c^+}} - m_{\Lambda_c^+}\right)^2 - m_{\Lambda_c^+}^2}$$





The residual between effective form factors data and the three-pole model is obtained:

$$\Delta|G_{\mathrm{eff}}|(p) = |G_{\mathrm{eff}}|(p) - G_{3p}(p)$$

and fitted to a damped oscillation model:

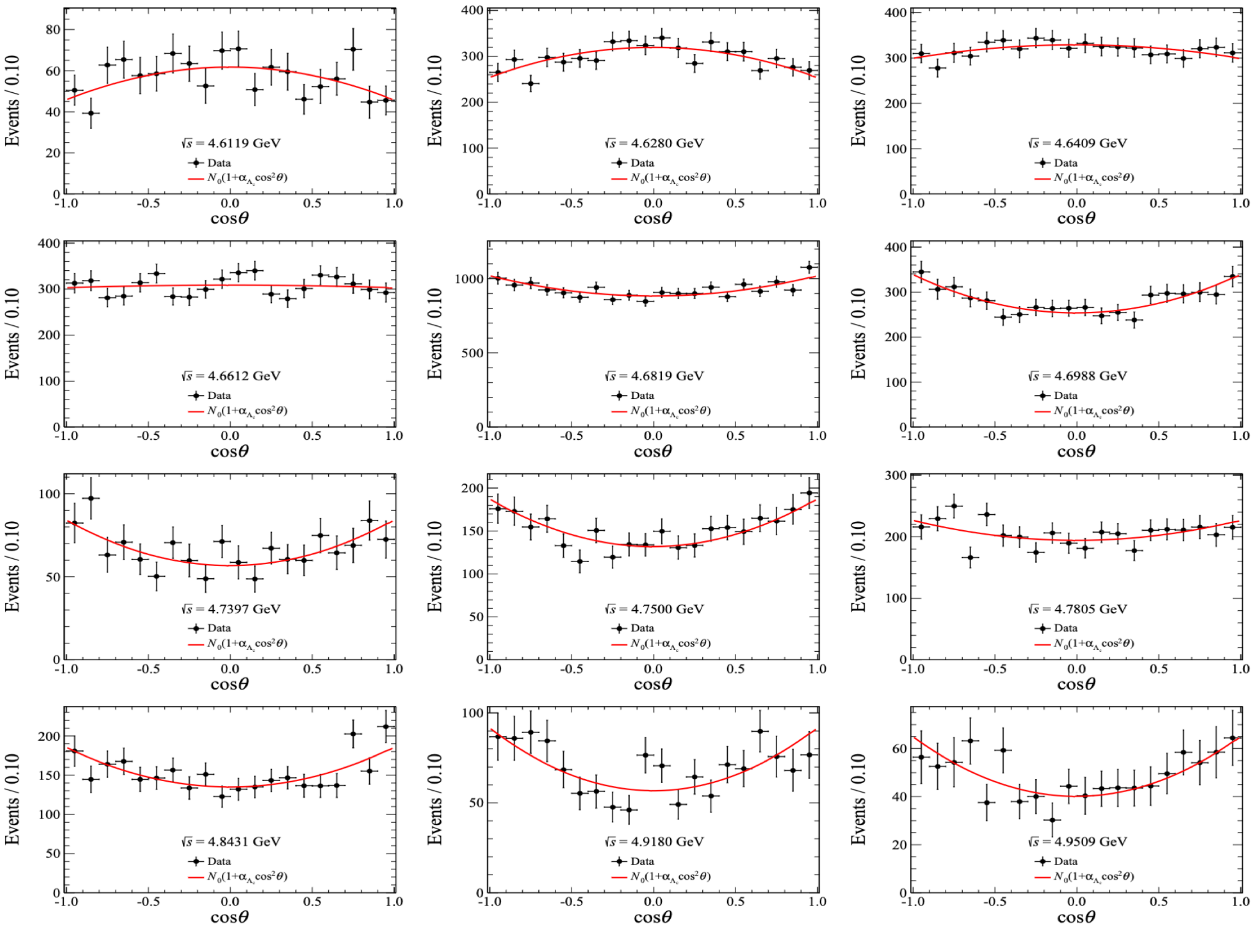
$$|G_{\mathrm{osc}}|(p) = Ae^{-Bp}\cos(Cp + D)$$

$$C = (0.03 \pm 0.14)\ (\mathrm{GeV}/c)^{-1}$$

No oscillation feature is discerned in the effective form-factor spectrum of Λ_c^+

Electromagnetic form factor of Λ_c^+

The $|G_E/G_M|$ of Λ_c^+ is studied by analyzing the polar angle distribution:



- One-photon exchange process is assumed
- An ISR correction is considered due to the contribution from ISR returned events
- Polar angle spectra is fitted with formula:

$$f(\cos\theta) \propto N_0\left(1+\alpha_{\Lambda_c}\cos^2\theta\right)$$

$$|G_E/G_M|^2 = \frac{s}{4m_{\Lambda_c^+}^2}\left(\frac{1-\alpha_{\Lambda_c}}{1+\alpha_{\Lambda_c}}\right)$$

The reversal of the angular distribution leads to $|G_E/G_M| < 1$

Electromagnetic form factor of Λ_c^+

Additional efforts are made to verify the angular analysis:

- Contribution from two-photon exchange (TPE) process is studied via the formula

$$f(\cos\theta) \propto N_0\left(1 + c_0\cos\theta + \alpha_{\Lambda_c}\cos^2\theta\right)$$

E. Tomasi-Gustafsson et al., PRC 103, 035203 (2021)

  where c_0 reflects the contribution from two-photon exchange process. Vanishing c_0 is obtained at each c.m. energy, no contribution from TPE process

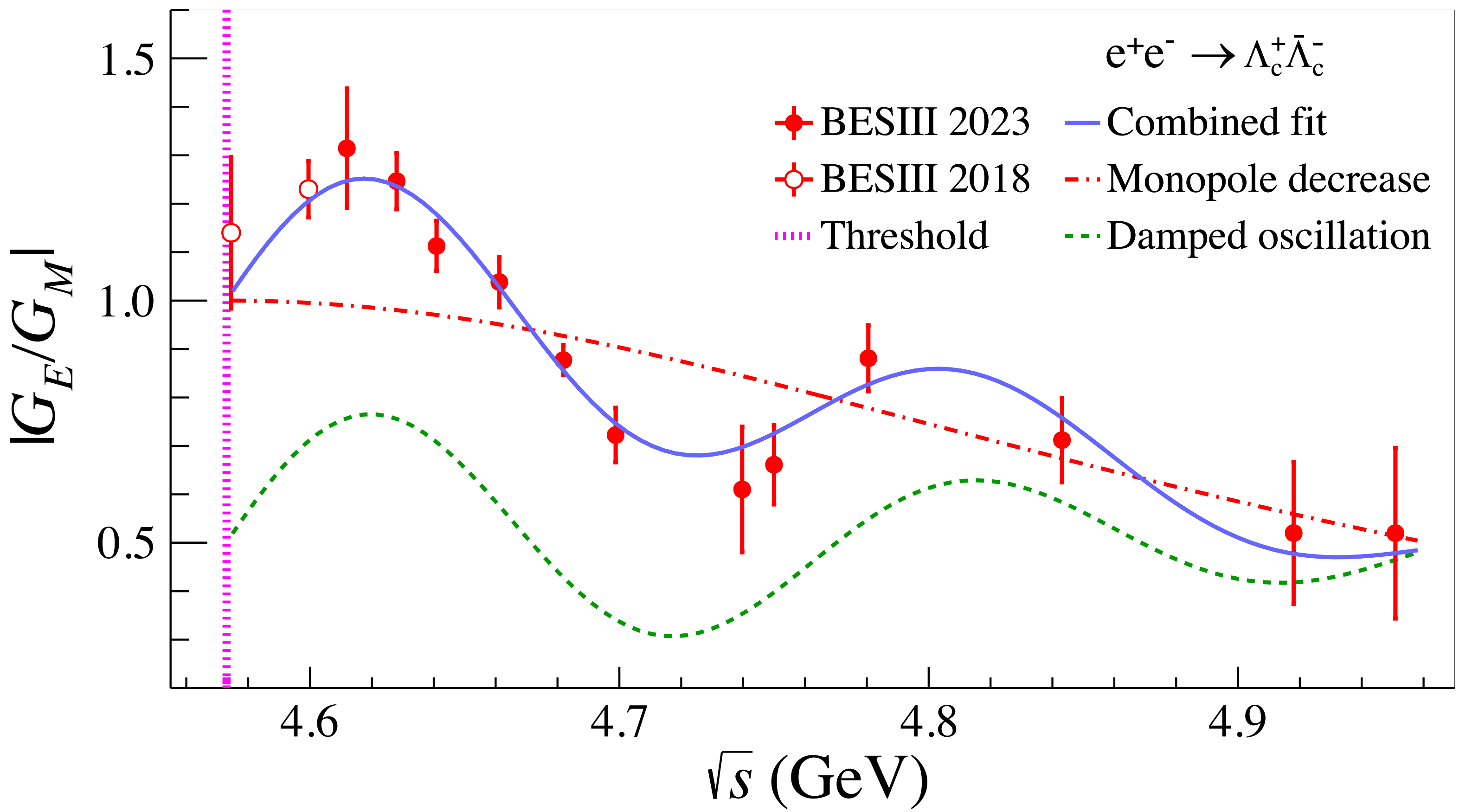
- Cross feed between different $\cos\theta$ bins are considered via performing an unfolding based on the signal MC samples, negligible effects to $|G_E/G_M|$

- Different binning scheme in terms of $\cos\theta$ is tested, including 8, 12, 16, 26, 32, and 40, no systematic deviation from the nominal case (20) is observed

- Sufficient input-output checks are carried out based on larger-statistic signal MC samples, the angular-analysis approach is valid

- A plenty of systematic effects are considered, the total uncertainty is dominated by the statistical one

Electromagnetic form factor of Λ_c^+

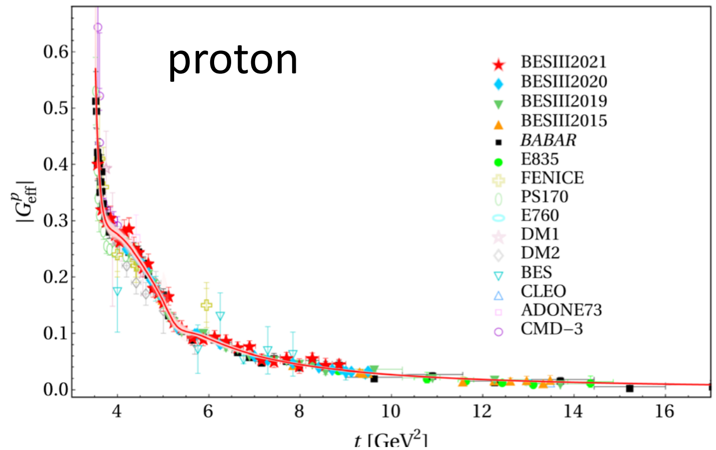


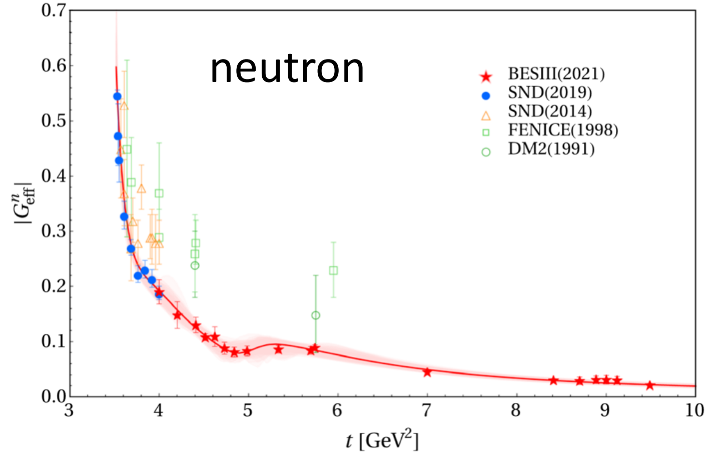
- Fitted to a function combining monopole decrease with damped oscillation
- Oscillation feature is unambiguously discerned for the charmed baryon Λ_c^+

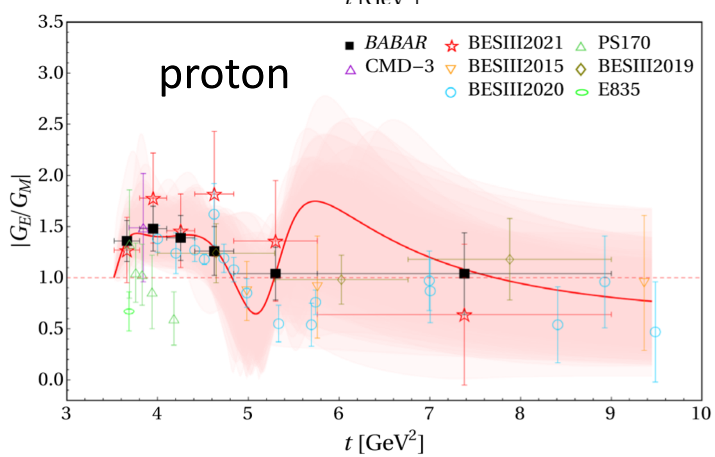
Where is the oscillation from?

Dispersion theory: broad poles above threshold in nucleon

Yong-Hui Lin, Hans-Werner Hammer, and Ulf-G. Meißner, Phys. Rev. Lett. **128**, 052002 (2022)







V_s	M_V	Γ_V	a_1^V	a_2^V
ω	0.783	0	0.701	0.338
ϕ	1.019	0	−0.526	−0.997
s_1	1.031	0	0.422	−2.827
s_2	1.120	0	0.122	3.655
s_3	1.827	0	0.955	−1.122
r_{s1}	1.903	0.973	−2.653	−1.753
r_{s2}	1.914	0.541	−3.069	2.017
r_{s3}	1.879	0.895	4.953	0.501

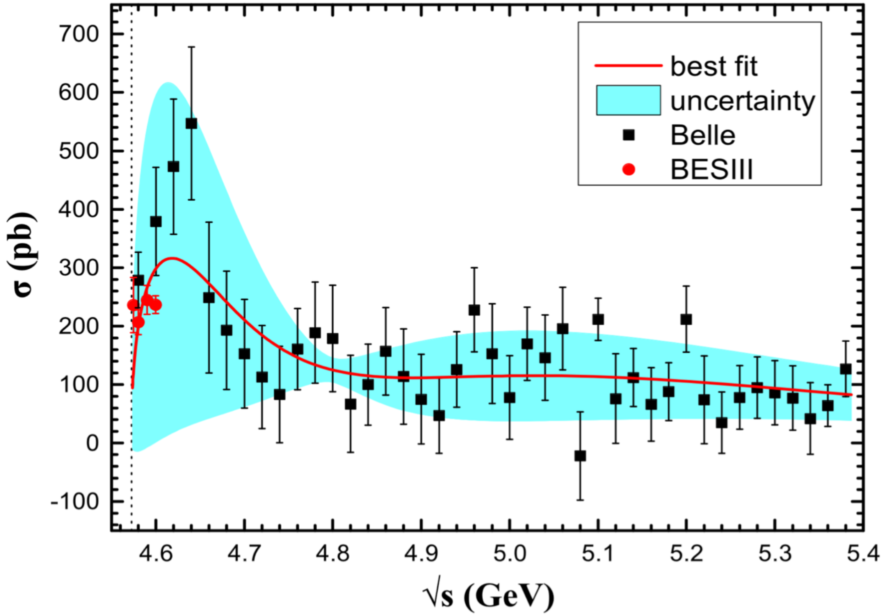
V_v	M_V	Γ_V	a_1^V	a_2^V
v_1	1.050	0	0.782	−0.132
v_2	1.323	0	−4.873	−0.645
v_3	1.368	0	3.518	−0.987
v_4	1.462	0	2.243	−3.813
v_5	1.532	0	−1.422	3.668
r_{v1}	2.256	0.239	2.552	−1.217
r_{v2}	2.253	0.245	−1.947	0.551
r_{v3}	2.220	0.362	−0.985	1.061

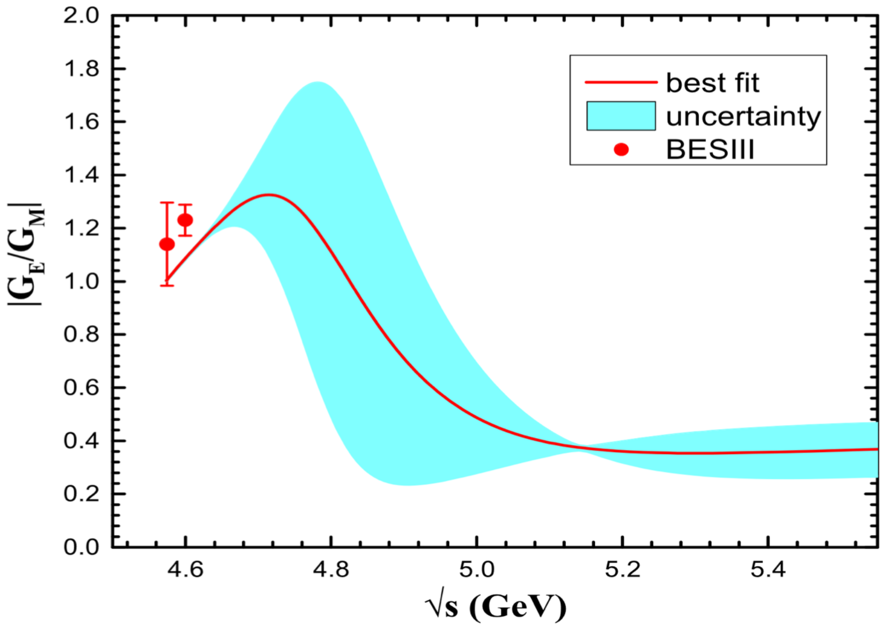
May not applicable for Λ_c^+ be since no oscillation feature is observed $|G_{\rm eff}|$ data

Where is the oscillation from?

A prediction of $|G_E|$ and $|G_M|$ based on the **modified VMD model** :

Junyao Wan, Yongliang Yang, and Zhun Lu, Eur. Phys. J. Plus 136, 949 (2021).





- $|G_E|$ and $|G_M|$ are parameterized separately with the modified VMD model
- Contribution from the vector charmed mesons and their excitations are included
- Phenomenology parameters are determined by fitting BESIII and Belle cross section data and BESIII $|G_E/G_M|$ data

Maybe difficult to simultaneously reproduce new BESIII cross section and $|G_E/G_M|$ data

Summary and outlook

- BESIII measured the cross section and electromagnetic form factors of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ with unprecedented precision
- The cross-section plateau is confirmed up to 4.66 GeV and the decay process $Y(4630) \to \Lambda_c^+\bar{\Lambda}_c^-$ is not observed
- Contradict to the case in proton and neutron, the oscillation feature is not observed in the $|G_{\mathrm{eff}}|$ spectrum of Λ_c^+
- Oscillation is discerned in $|G_E/G_M|$ distribution of Λ_c^+, but with a significantly different frequency from that of proton

It is likely that these two oscillations come from different origins

Summary and outlook

- BESIII will collect data at energies up to 5.6 GeV, more charmed baryons, such as Λ_c^*, Σ_c, Ξ_c and Ω_c, could be studied

Chin. Phys. C 44, 04001 (2020)

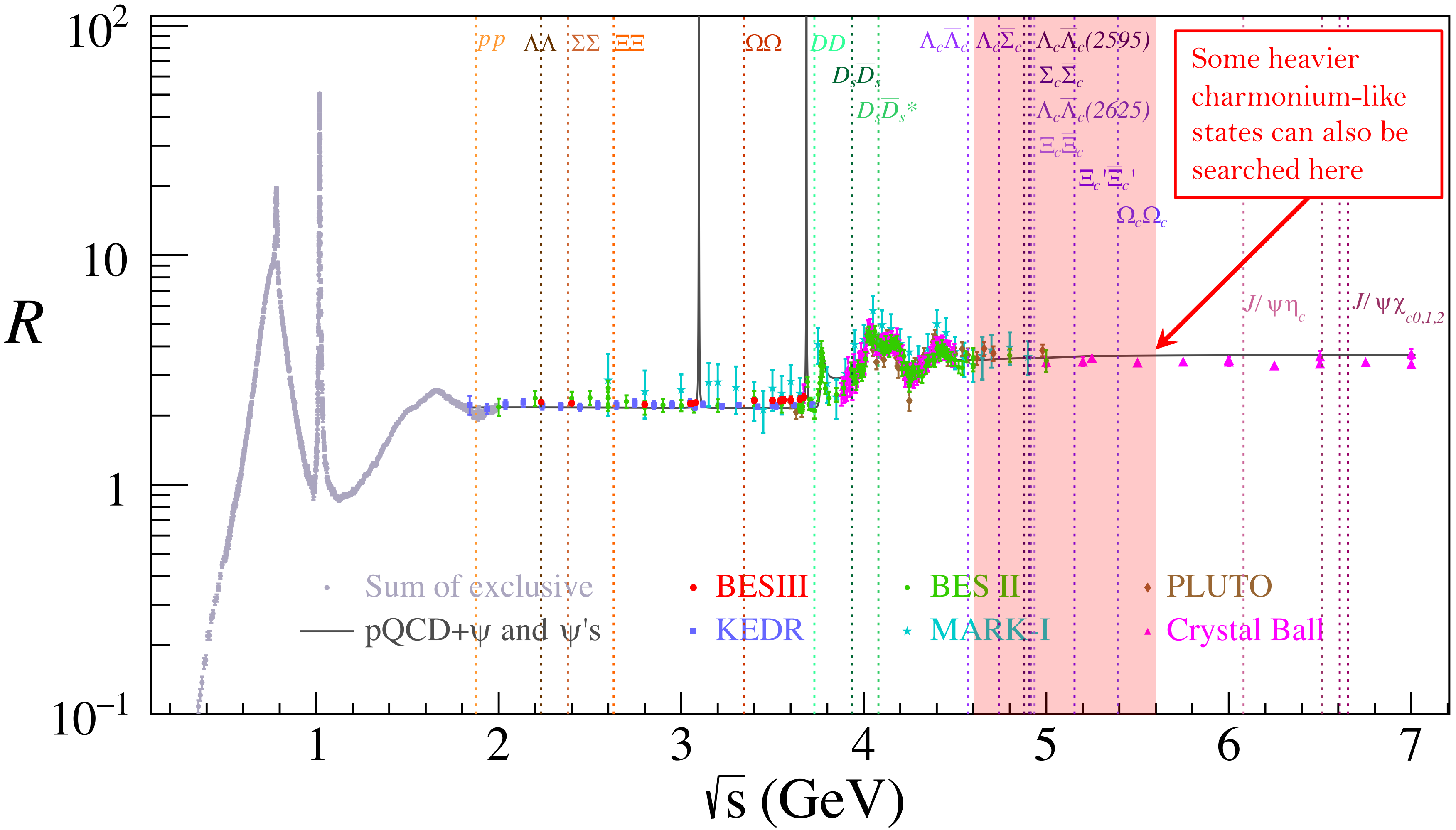
Table 7.1: List of data samples collected by BESIII/BEPCII up to 2019, and the proposed samples for the remainder of the physics program. The most right column shows the number of required data taking days in current (T_C) or upgraded (T_U) machine. The machine upgrades include top-up implementation and beam current increase.

Energy	Physics motivations	Current data	Expected final data	T_C / T_U
1.8 - 2.0 GeV	R values Nucleon cross-sections	N/A	0.1 fb^{-1} (fine scan)	60/50 days
2.0 - 3.1 GeV	R values Cross-sections	Fine scan (20 energy points)	Complete scan (additional points)	250/180 days
J/ψ peak	Light hadron & Glueball J/ψ decays	3.2 fb^{-1} (10 billion)	3.2 fb^{-1} (10 billion)	N/A
$\psi(3686)$ peak	Light hadron & Glueball Charmonium decays	0.67 fb^{-1} (0.45 billion)	4.5 fb^{-1} (3.0 billion)	150/90 days
$\psi(3770)$ peak	$D^0/D^\pm$ decays	2.9 fb^{-1}	20.0 fb^{-1}	610/360 days
3.8 - 4.6 GeV	R values XYZ/Open charm	Fine scan (105 energy points)	No requirement	N/A
4.180 GeV	D_s decay XYZ/Open charm	3.2 fb^{-1}	6 fb^{-1}	140/50 days
4.0 - 4.6 GeV	XYZ/Open charm Higher charmonia cross-sections	16.0 fb^{-1} at different $\sqrt{s}$	30 fb^{-1} at different $\sqrt{s}$	770/310 days
4.6 - 4.9 GeV	Charmed baryon/XYZ cross-sections	0.56 fb^{-1} at 4.6 GeV	15 fb^{-1} at different $\sqrt{s}$	1490/600 days
4.74 GeV	$\Sigma_c^+\bar{\Lambda}_c^-$ cross-section	N/A	1.0 fb^{-1}	100/40 days
4.91 GeV	$\Sigma_c\bar{\Sigma}_c$ cross-section	N/A	1.0 fb^{-1}	120/50 days
4.95 GeV	Ξ_c decays	N/A	1.0 fb^{-1}	130/50 days

A refined energy-scan will always help for the study of the $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ process!

Summary and outlook

- BESIII will collect data at energies up to 5.6 GeV, more charmed baryons, such as Λ_c^*, Σ_c, Ξ_c and Ω_c, could be studied



Summary and outlook

Thank you!

Summary and outlook

- BESIII will collect data at energies up to 5.6 GeV, more charmed baryons, such as Λ_c^*, Σ_c, Ξ_c and Ω_c, could be studied