Baryon form factors at BESIII

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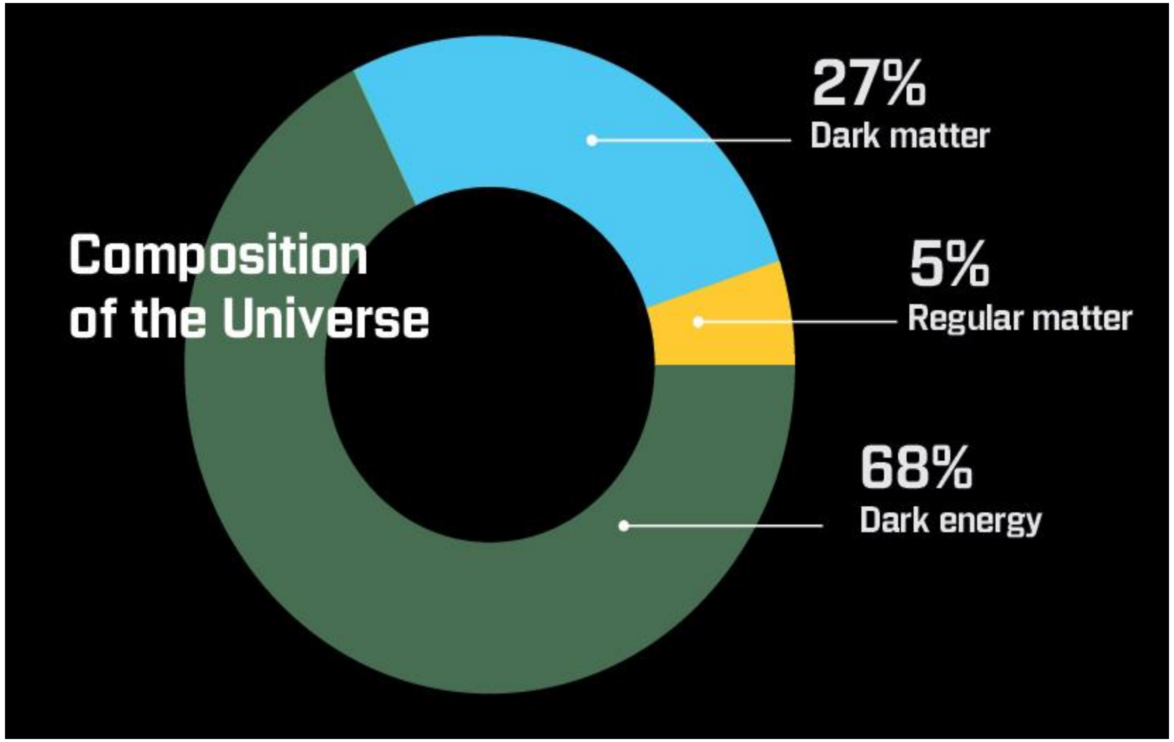
Outline

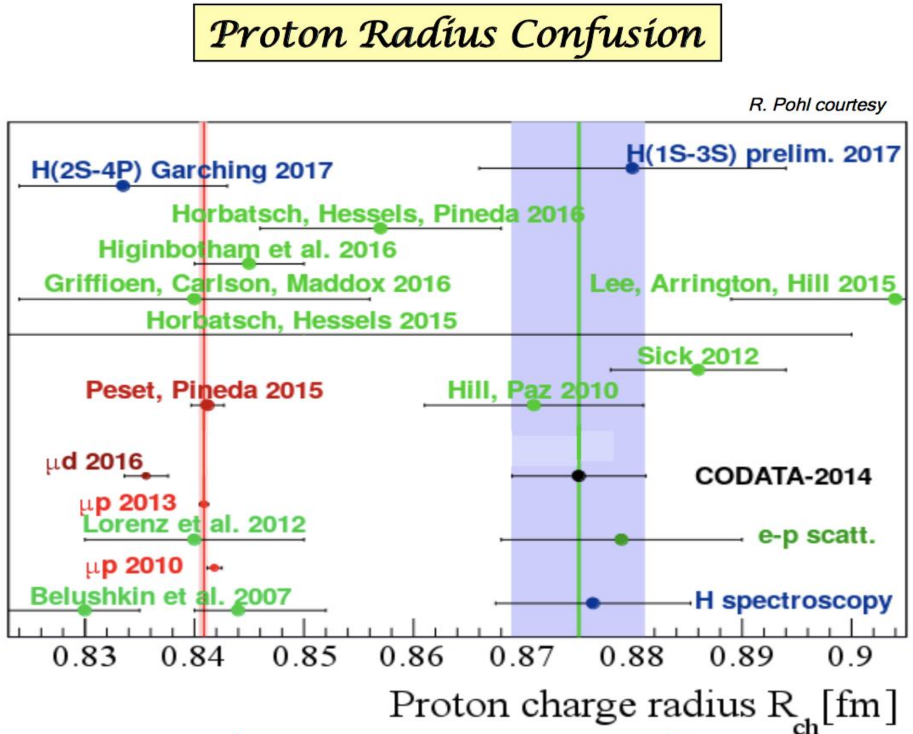
- Introduction
- Baryon Form factors
    - Nucleon form factors
    - Hyperon form factors
- Summary

Composition of the Universe



NASA

- Nucleon is the dominant component of visible universe (>

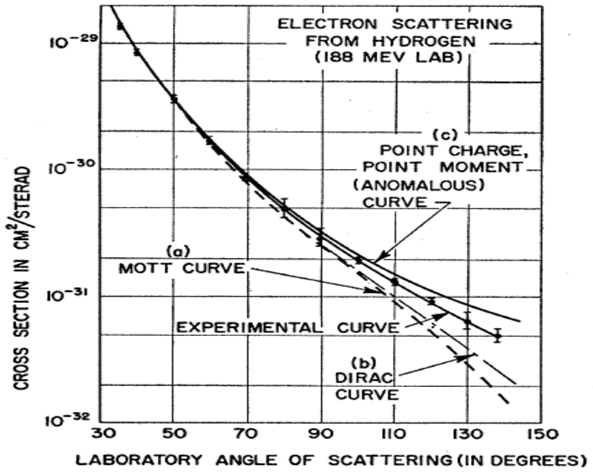


Need for more data !!

- Probe nucleon charge radius:

$$G_E(Q^2) = 1 - \frac{1}{6} r_E^2 Q^2 + \cdots$$ （Q：四动量转移）

Nucleon Electromagnetic Form Factor (NEFF)

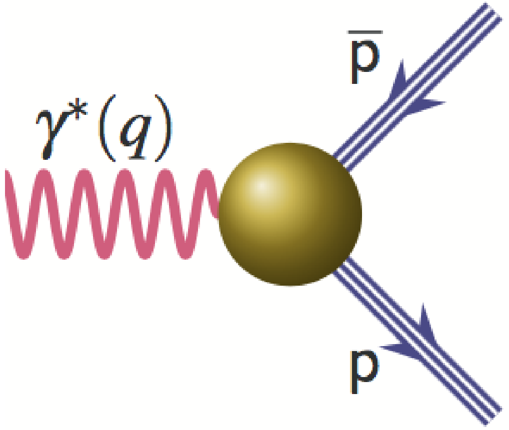


- Elastic scattering of electron and proton (Hofstadter, Nobel Prize 1961)
  - Theoretically, differential cross section is:

$$\left(\frac{d\sigma}{d\Omega}\right)_{ep} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} (1 + 2\tau\tan^2\frac{\theta}{2})F(q^2)$$

- The nucleon electromagnetic vertex Γ_μ describing the hadron current:

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



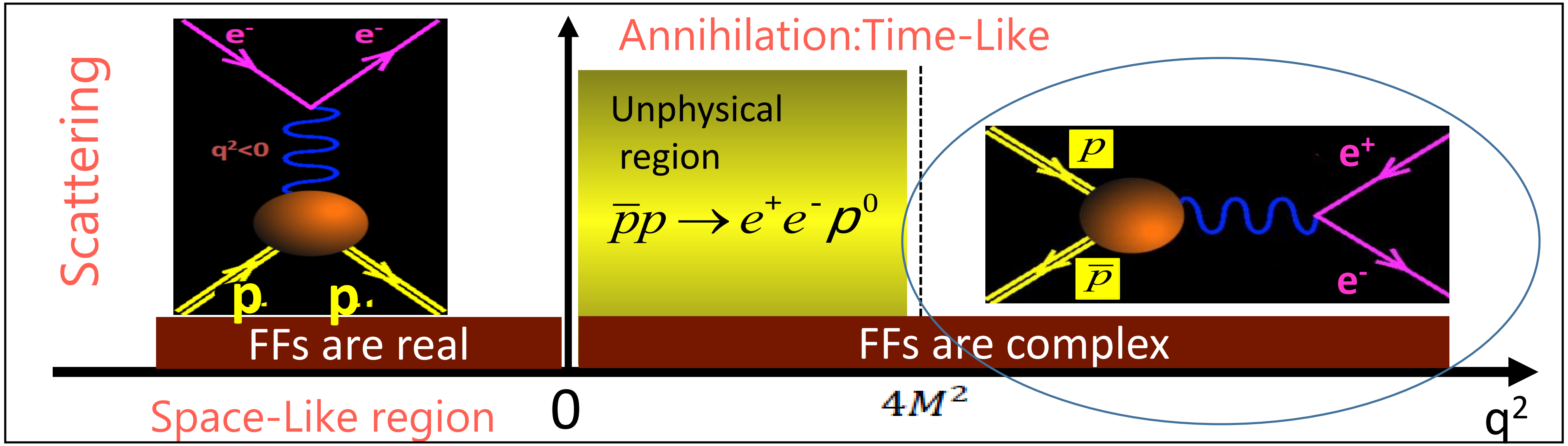
- Sachs FFs:

电形状因子：$G_E(q^2) = F_1(q^2) + \tau\kappa_p F_2(q^2)$

磁形状因子：$G_M(q^2) = F_1(q^2) + \kappa_p F_2(q^2)$

$$\tau = \frac{q^2}{4m^2}, \quad \kappa = \frac{g-2}{2}, \quad g = \frac{\mu}{J}$$

Playground of NEFFs



- BESIII measured the FFs in TL
- Test QCD-based theories: VMD, pQCD, chPT, lattice QCD…

- In SL, FFs is real.
- In TL, FFs can be complex, $|G_E/G_M|$ and $\Delta\Phi$.

Measurement techniques for baryon FF

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

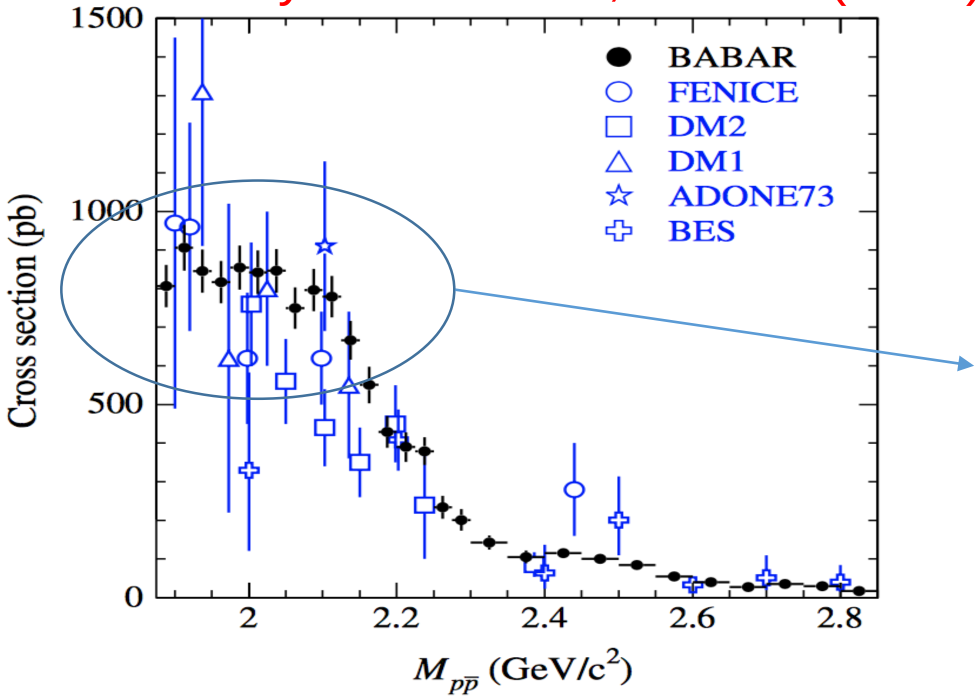
$\sim \frac{1}{400}$

Both techniques, energy scan and initial state radiation. can be used at BESIII

Status on proton FFs

- Still mystery on proton cross section line-shape

Phys. Rew. D 87, 092005 (2013)

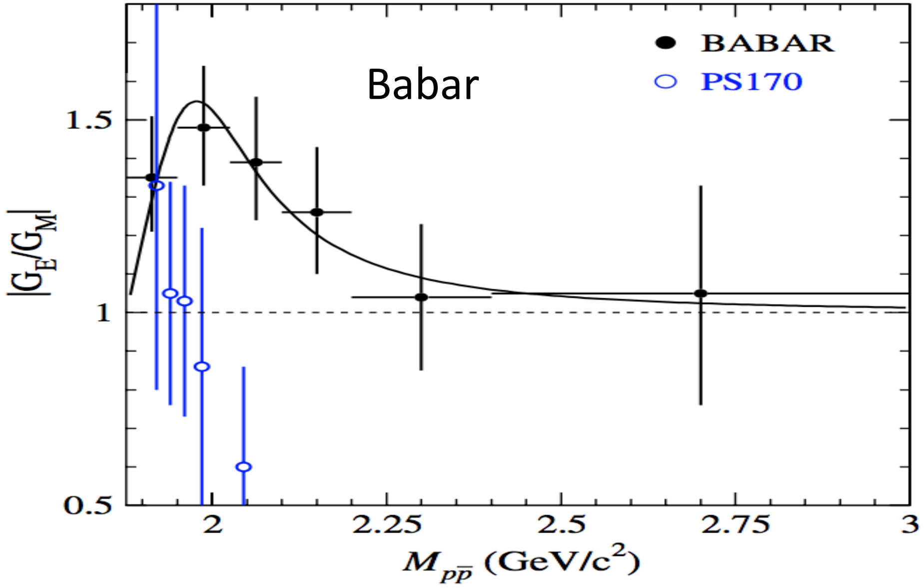


- Point-like cross section near threshold,
- $\sigma_{\text{point}} = \frac{\pi\alpha^2}{3m^2\tau}[1 + \frac{1}{2\tau}]$

Status on proton FFs

- Inconsistence on $|G_E/G_M|$ of proton & poor precision

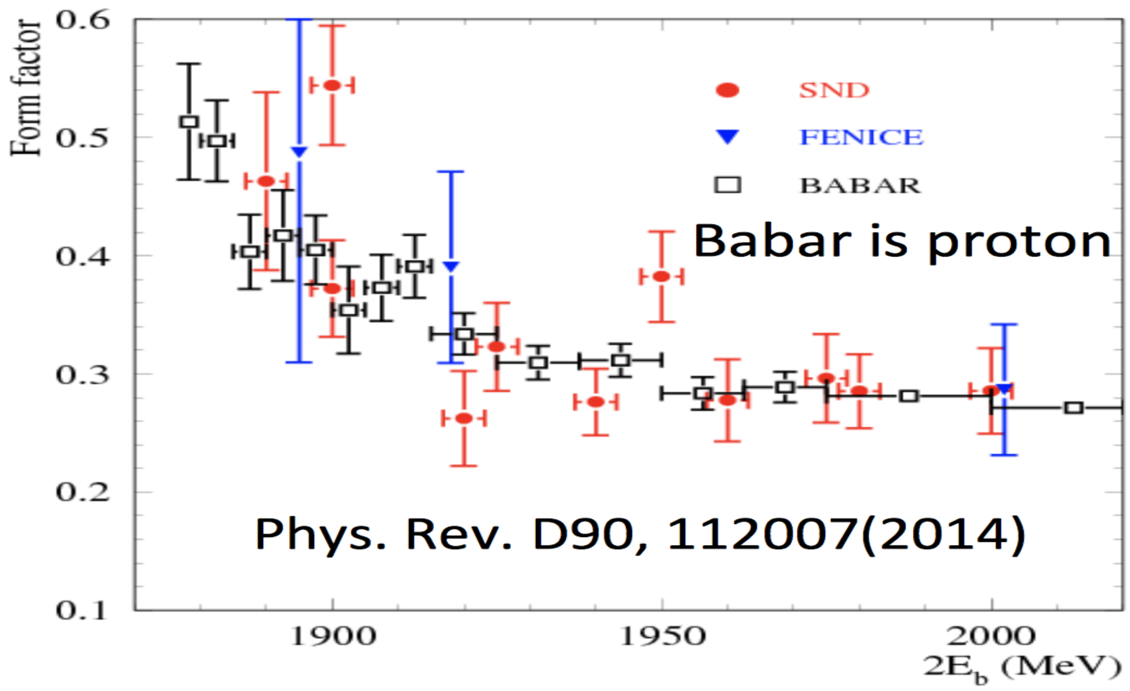
Phys. Rew. D 87, 092005 (2013)



- pQCD predictes a continuous transition and SL-TL equality at high Q^2
- SL best accuracy in $Q^2(0.5, 8.5)$ GeV^2: 1.7%
- TL accuracy before BESIII: exceeding 10%

Status on neutron FFs

- Poor precision, limited q^2 range in neutron FF



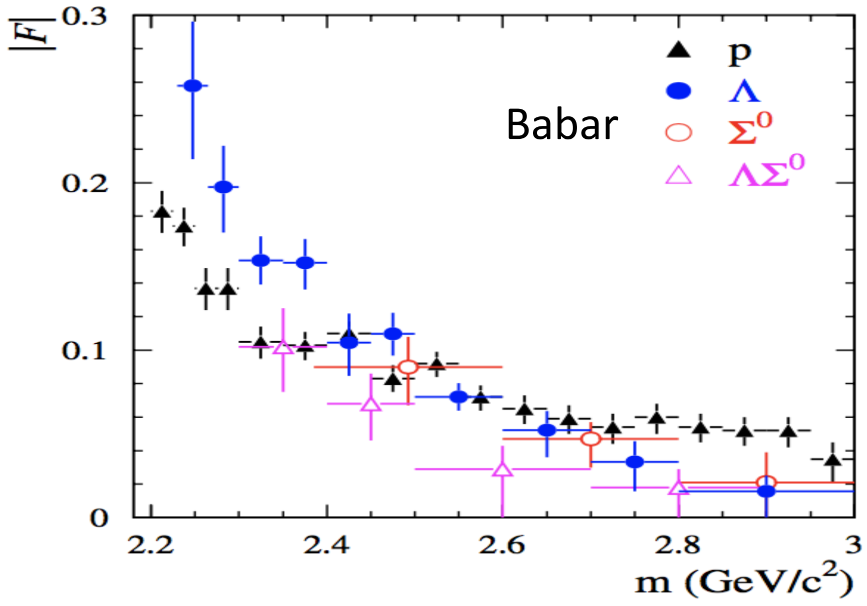
- pQCD prediction[1]: $|\frac{G_M^n}{G_M^p}|^2 \approx (\frac{q_d}{q_u})^2 = 0.25$
- VMD prediction[2]: $|\frac{G_M^n}{G_M^p}|^2 \approx 1$

[1] V. L. Chernyak and I. R. Zhitnitsky, Nucl. Phys. B 246 (1984) 52.
[2] J. G. Körner and m. Kuroda, Phys. Rev. D 16 (1988) 2165.

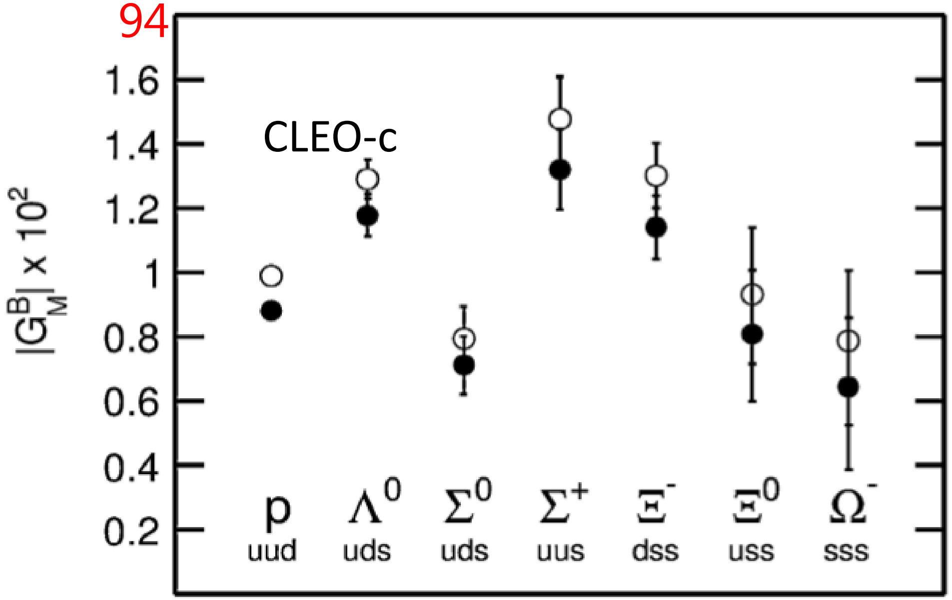
Status on hyperon FFs

- Rare experimental results on Hyperon FF

Phys. Rev. D **76,** 092006 (2007)



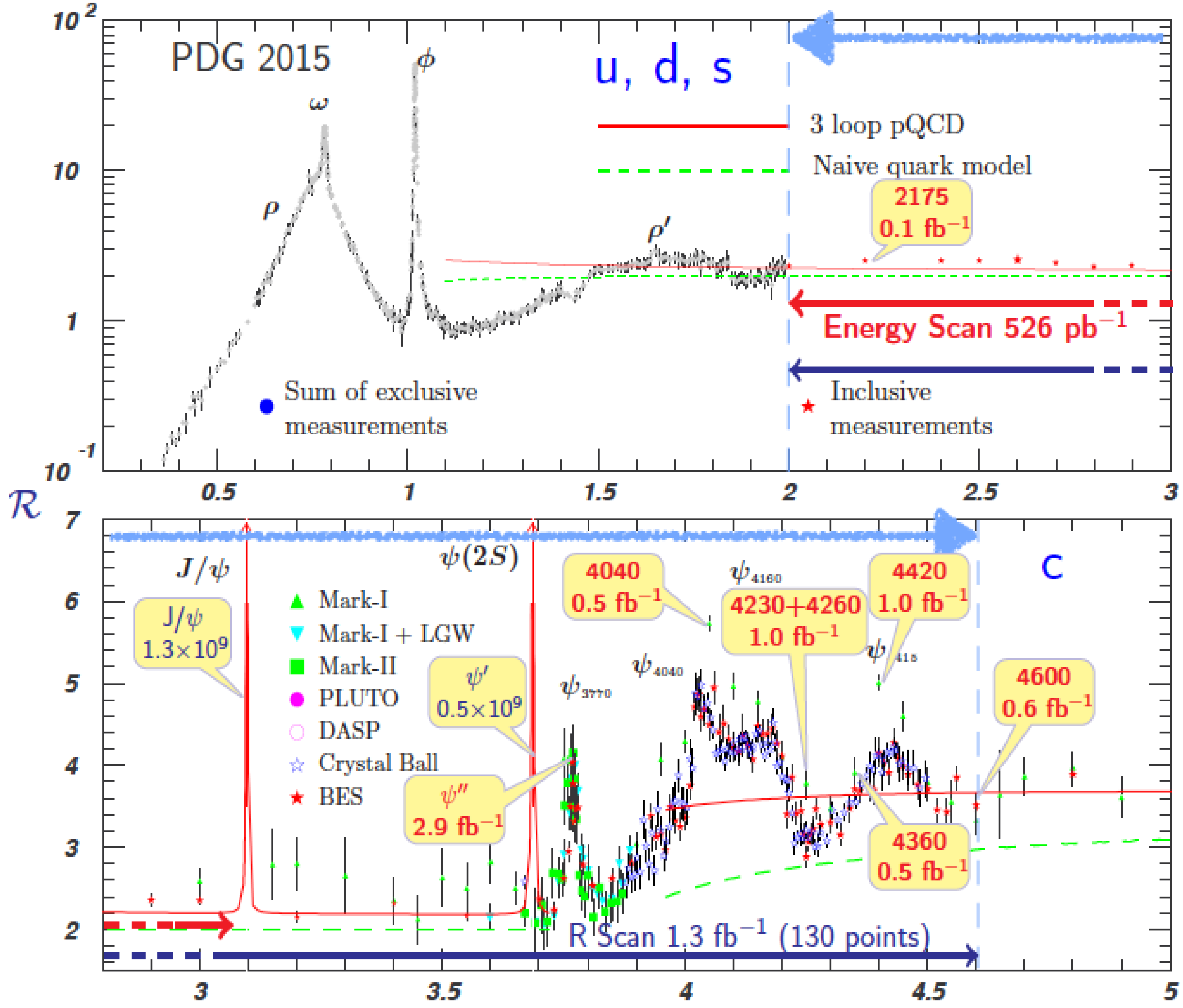
Phys. Lett. B 739 (2014) 90–94

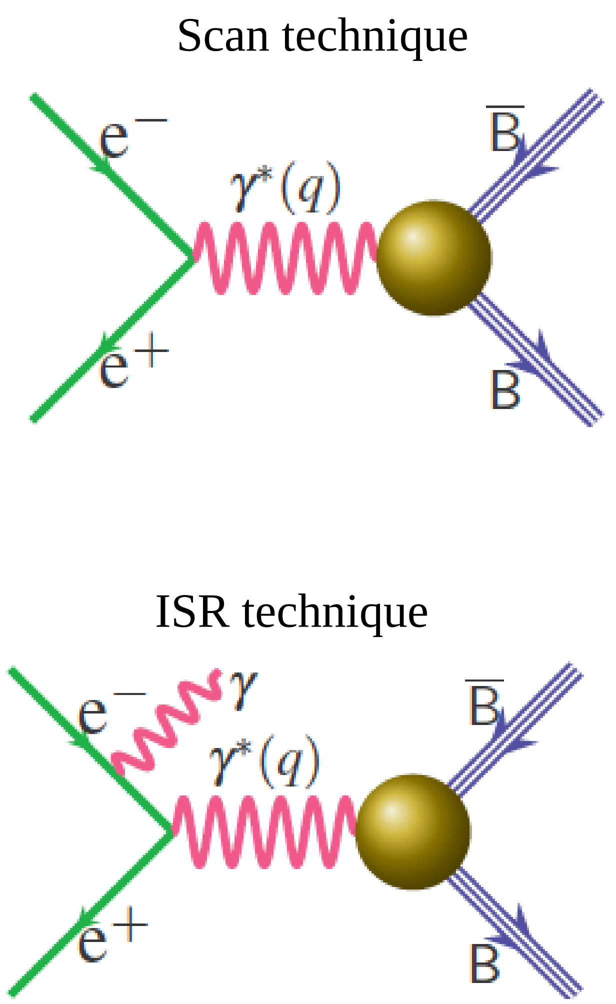


q^2=14.2 GeV^2

- diquark correlation evidence
- favor spin–isospin singlet

BESIII data samples

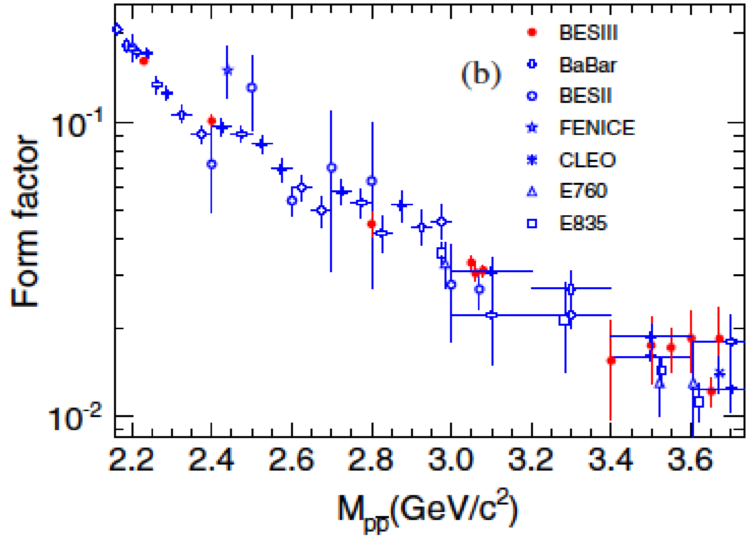


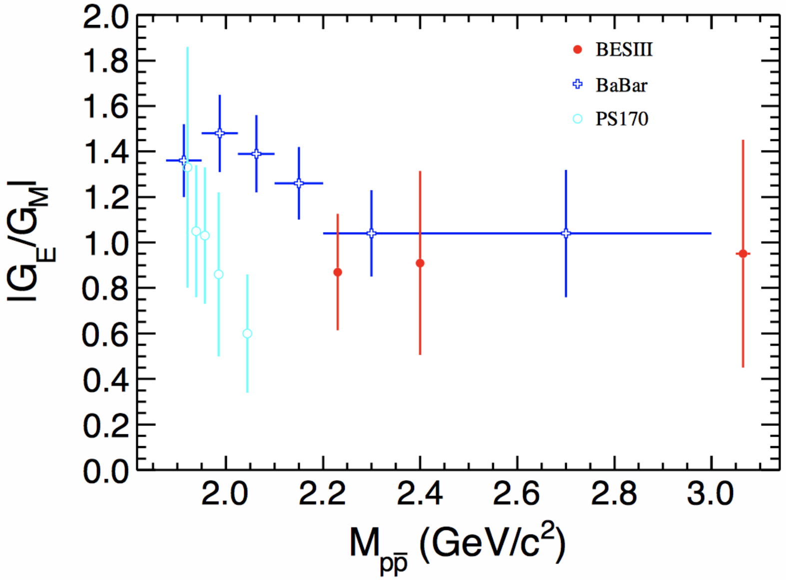


Proton FFs with scan technique

Phys. Rev. D91, 112004 (2015)

- 12 energy points from $\sqrt{s}$ =2.2324-3.671, L_{int}: 156.9 pb^{-1}





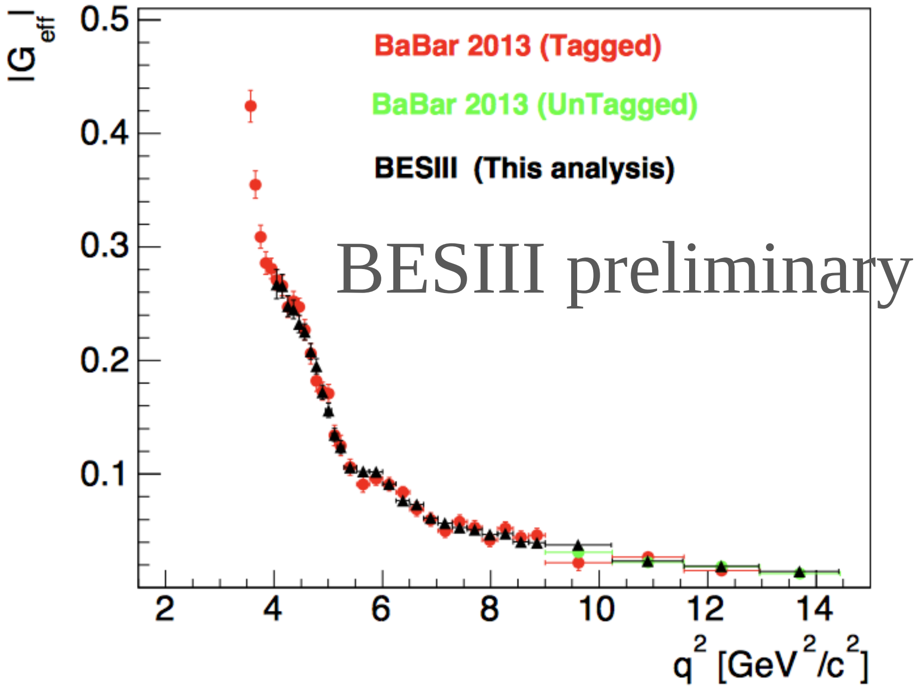
- Effective FFs consistent with Babar, improved precision
- Confirm Babar results above on $\sqrt{s}$ =2.0 GeV on $|G_E/G_M|$ ratio

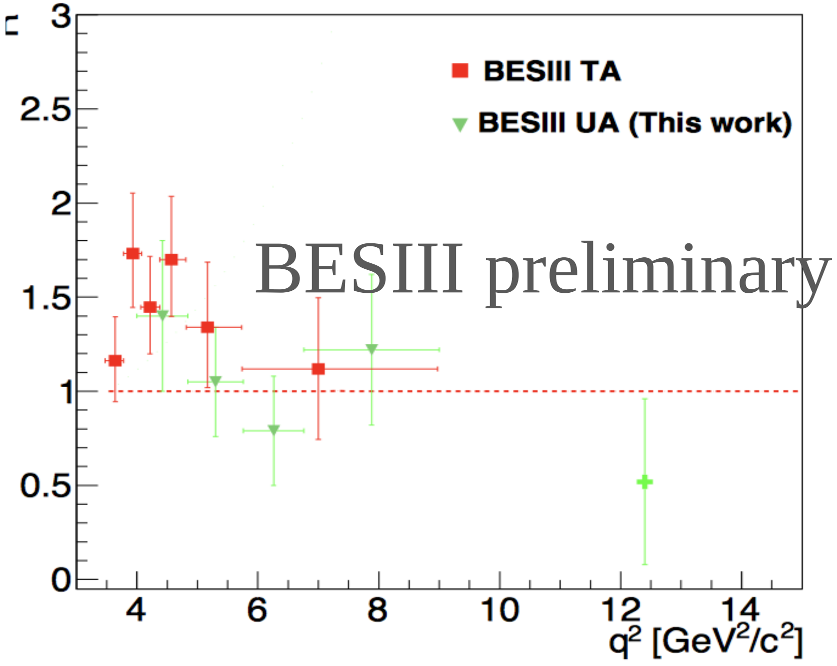
Prospects:

- Precise measurement of proton FFs with larger scan data set.
- Expected best accuracy of $|\frac{G_E}{G_M}|$, best accuracy<3%.

Proton FFs with ISR technique

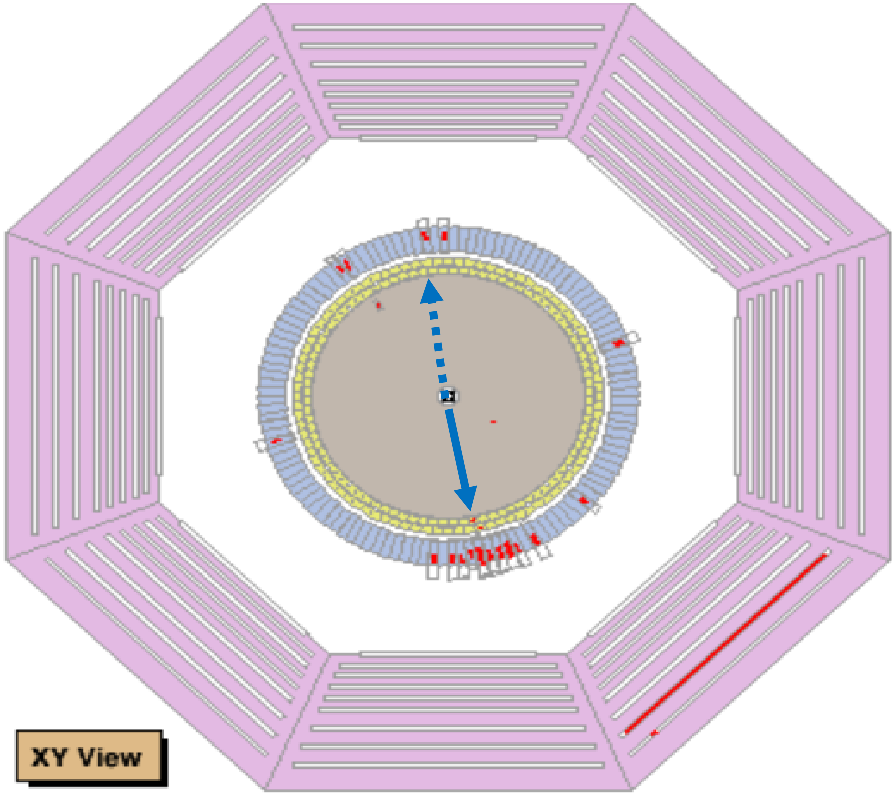
- Combined seven data samples (7.4 fb^{-1})





- Precision on $|G_{eff}|$: 4.6%-30.4%(tagged), 4.1%-28.7%(untagged)
- Precision $|G_E/G_M|$ ratio: 19.1%-35.3%, (tagged), 23.0%-31.4%(untagged)
- Confirm Babar's result on $|G_E/G_M|$ above threshold

Neutron form factors at BESIII



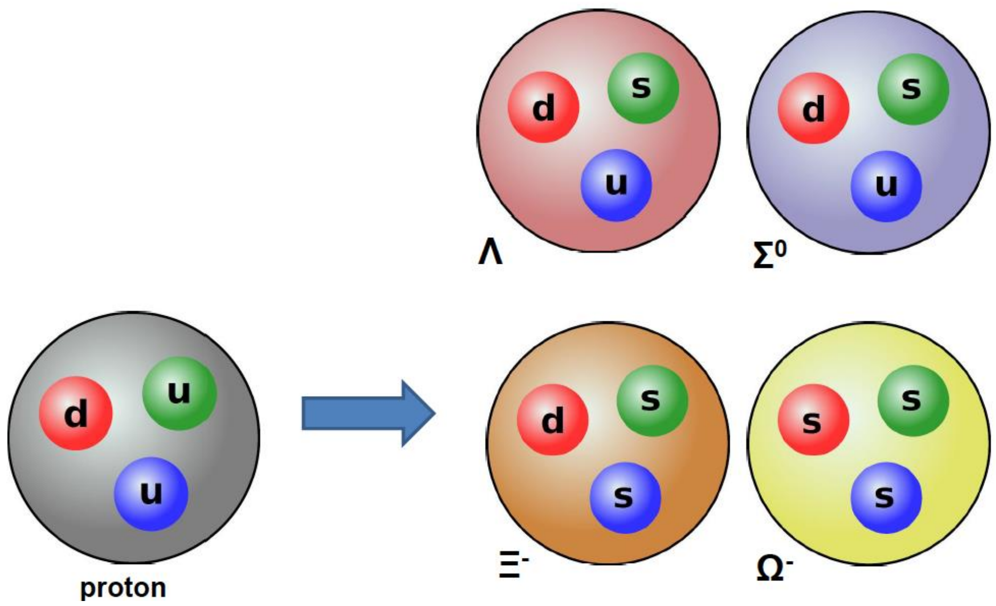
- Reconstruction of $e^+e^- \to n\bar{n}$
- Challenge:
  - Little information on EMC
  - Hugh background(Bhabha, digam)
  - No available event start time
  - Trigger efficiency is threatened.

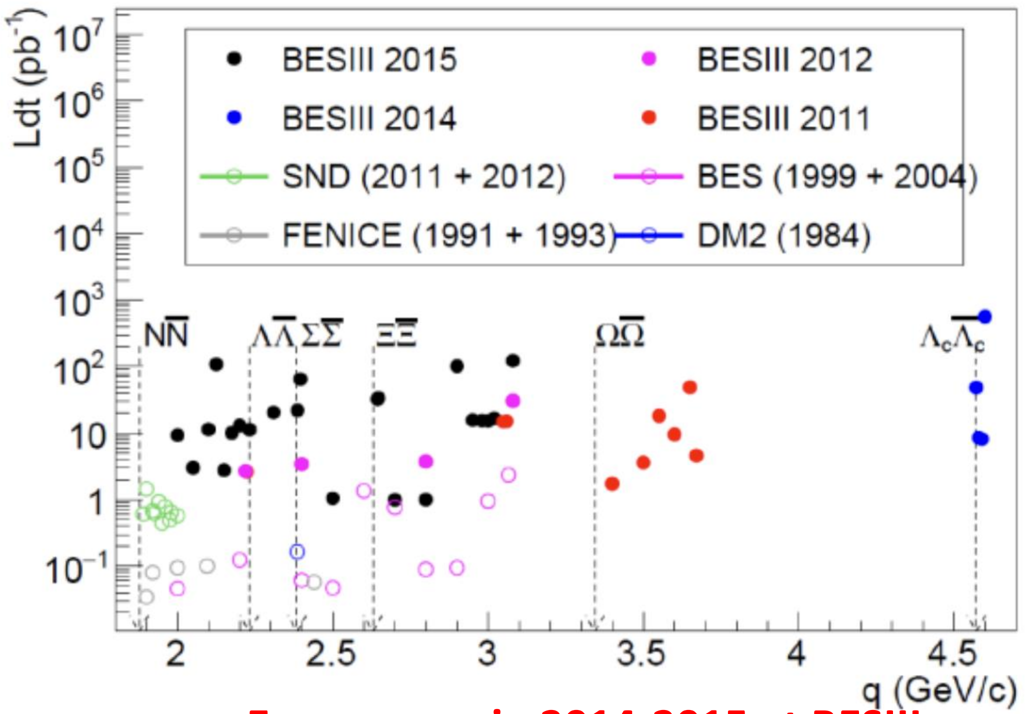
Prospects:

- BESIII new result ($\sqrt{s}$=2.0 to 3.08 GeV) on Neutron Form Factor is foreseen with high precision (best accuracy < 10%).
- Measured $\left|\frac{G_E}{G_M}\right|$ ratio for the first time.

Threshold effect

- Hyperon pair production:
  - Possibility to reconstruct hyperon pair production much close to threshold than the proton



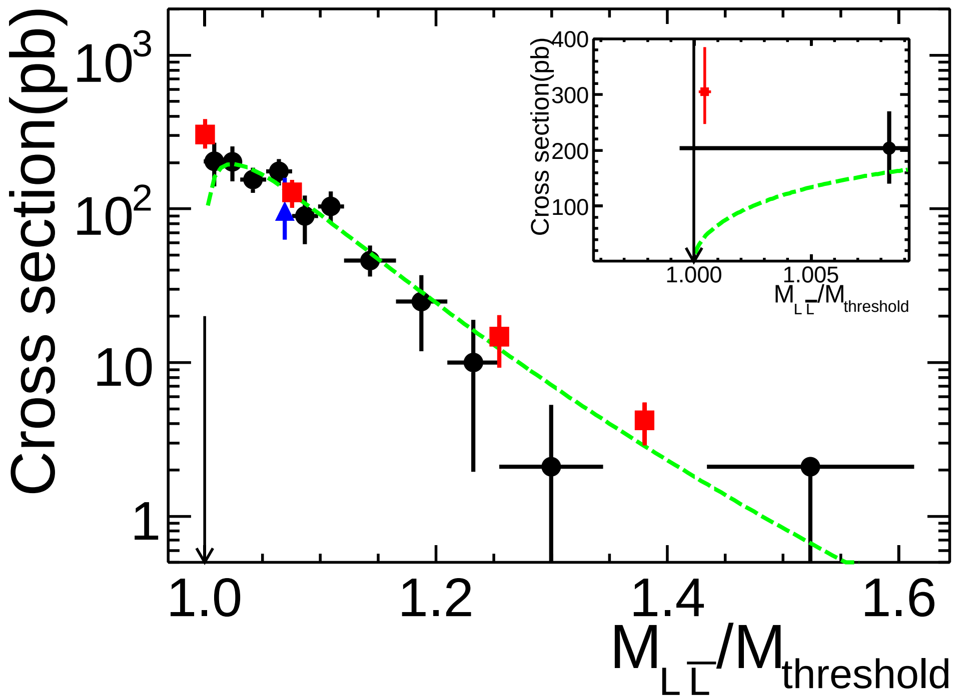


Energy scan in 2014-2015 at BESIII

Measurement of $e^+e^- \to \Lambda\bar{\Lambda}$ at $\sqrt{s}$ =2.2324 GeV

Phys. Rev. D 97, 032013 (2018)

- Near threshold production ($2M_\Lambda$ +1.0 MeV) and small PHSP in $\Lambda/\bar{\Lambda}$ decays
- Indirect search for antiproton in $\boldsymbol{\Lambda \to p\pi^-, \bar{\Lambda} \to \bar{p}\pi^+}$
- Search for mono-energetic π^0 in $\boldsymbol{\bar{\Lambda} \to \bar{n}\pi^0}$



- The anomalous behavior differing from the pQCD prediction at threshold is observed.

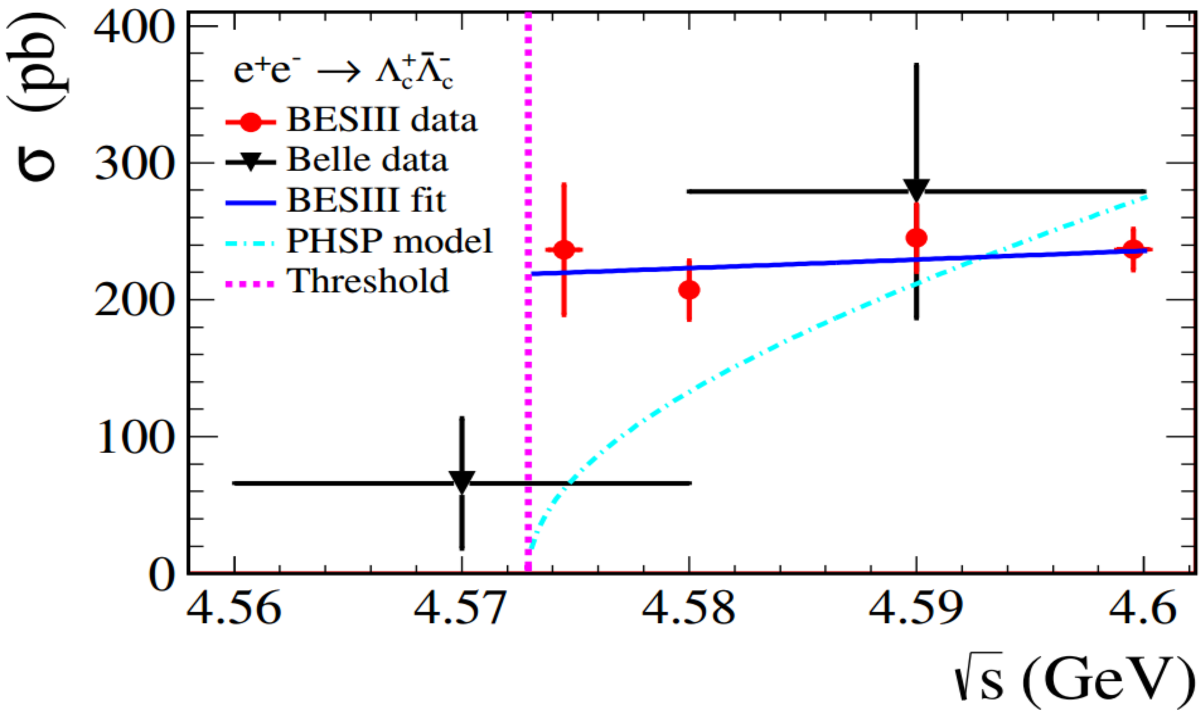
•Recalling the baryon pair production cross section:

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

•The Columb correction factor C=$\frac{\pi\alpha}{\beta}\frac{1}{1-\exp(-\frac{\pi\alpha}{\beta})}$(Q), cancel the β for a charged $B\bar{B}$ pair, equals to 1 for a neutral $B\bar{B}$ pair

$e^+e^- \rightarrow \Lambda_c^+\bar{\Lambda}_c^-$ near kinematic threshold

Phys. Rev. Lett. 120, 132001 (2018)

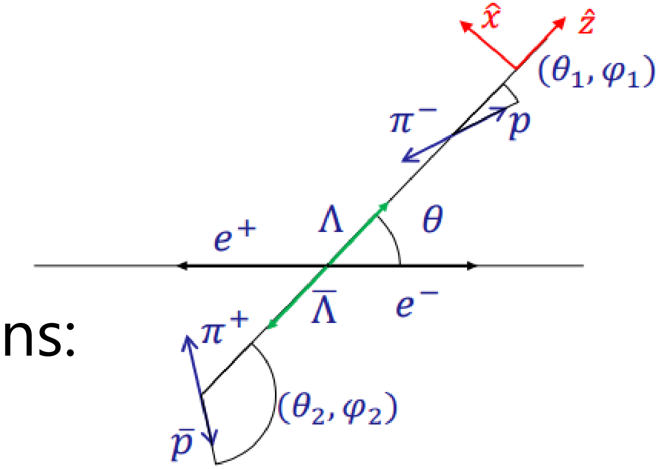


Prospects:

- More results on Hyperon FFs will come out ($\Sigma\bar{\Sigma}$, $\Lambda\bar{\Sigma}$, $\Xi\bar{\Xi}$ ...)

- Ten modes of $\boldsymbol{\Lambda_c^+}$ ($\boldsymbol{\bar{\Lambda}_c^-}$) are reconstructed
- Measurement of the Born cross section at 4 energy points below 4.6 GeV with **unprecedented statistical accuracy** (~1.3% at 4.6 GeV)

Relative phase of Λ



- Complex form of FFs:
  - $G_E = |G_E|e^{i\Phi_E}$, $G_M = |G_M|e^{i\Phi_M}$
  - Relative phase: $\Delta\Phi = \Phi_E$-Φ_M
- A non-zero phase has polarization effect on the Baryons:
  - $P_y \propto \sin\Delta\Phi$
- The angular distribution of daughter baryon from Hyperon weak decay is:
  - $\frac{d\sigma}{d\Omega} \propto 1 + \alpha_\Lambda \boldsymbol{P_y} \cdot \hat{\boldsymbol{q}}$
  - α_Λ: asymmetry parameter
  - $\hat{q}$: unit vector along the daughter baryon in hyperon rest frame

With hyperon weak decay to B+P, the polarization of hyperon can be measurement, so does the relative phase between G_E and G_M !

Relative phase of Λ

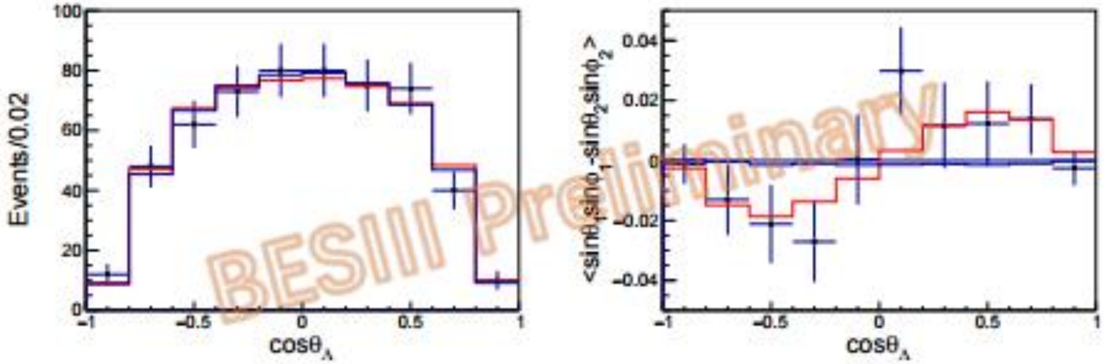
- An event of the reaction $e^+e^- \to \Lambda(\to p\pi^-)\bar{\Lambda}(\to \bar{p}\pi^+)$ is specified by the five dimensional vector $\xi = (\theta, \Omega_1, \Omega_2)$, the differential cross section is:

Phys.Lett. B772 (2017) 16-20

$$\mathscr{W}(\xi) = \mathscr{T}_0(\xi) + \eta\,\mathscr{T}_5(\xi)$$
$$-\alpha_\Lambda^2\left(\mathscr{T}_1(\xi) + \sqrt{1-\eta^2}\cos(\Delta\Phi)\,\mathscr{T}_2(\xi) + \eta\,\mathscr{T}_6(\xi)\right)$$
$$+\alpha_\Lambda\sqrt{1-\eta^2}\sin(\Delta\Phi)\left(\mathscr{T}_3(\xi) - \mathscr{T}_4(\xi)\right).$$

$$\mathscr{T}_0(\xi) = 1$$
$$\mathscr{T}_1(\xi) = \sin^2\theta \sin\theta_1 \sin\theta_2 \cos\phi_1 \cos\phi_2 + \cos^2\theta \cos\theta_1 \cos\theta_2$$
$$\mathscr{T}_2(\xi) = \sin\theta \cos\theta\,(\sin\theta_1 \cos\theta_2 \cos\phi_1 + \cos\theta_1 \sin\theta_2 \cos\phi_2)$$
$$\mathscr{T}_3(\xi) = \sin\theta \cos\theta \sin\theta_1 \sin\phi_1$$
$$\mathscr{T}_4(\xi) = \sin\theta \cos\theta \sin\theta_2 \sin\phi_2$$
$$\mathscr{T}_5(\xi) = \cos^2\theta$$
$$\mathscr{T}_6(\xi) = \cos\theta_1 \cos\theta_2 - \sin^2\theta \sin\theta_1 \sin\theta_2 \sin\phi_1 \sin\phi_2.$$

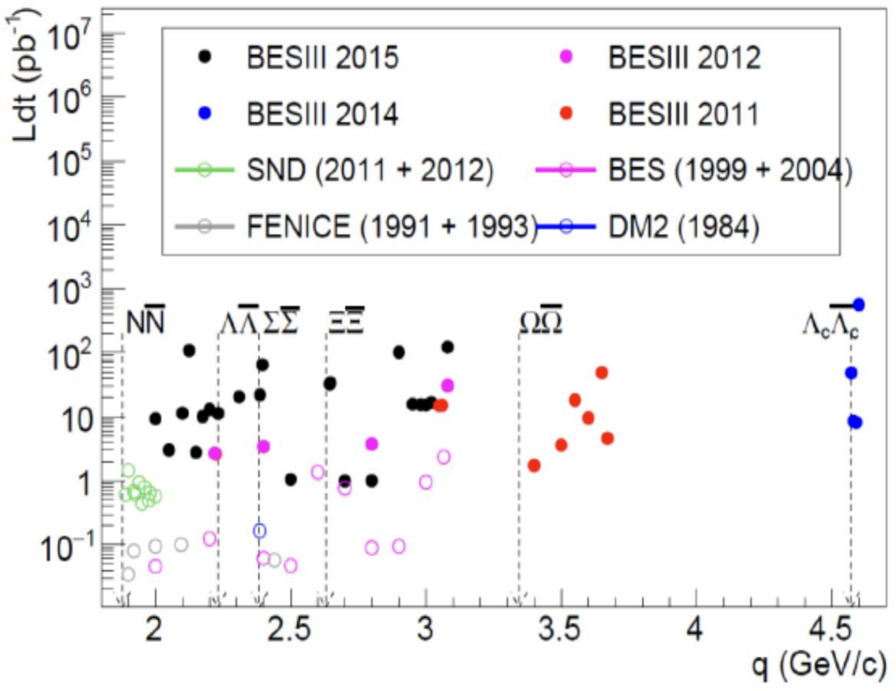
Fit data by Maximum Log Likelihood



$$\left|\frac{G_E}{G_M}\right| = 0.94 \pm 0.16(stat.) \pm 0.03(sys.) \pm 0.02(\alpha_\Lambda)$$
$$\Delta\Phi = 42^\circ \pm 16^\circ(stat.) \pm 8^\circ(sys.) \pm 6^\circ(\alpha_\Lambda)$$

Summary and discussion

- Nucleon FFs is measured with scan and ISR techniques at BESIII
  - Answered the remaining questions on proton
  - Precise measurement on neutron FFs is ongoi
- With the large data set, more precise results on Hyperon FFs are expected on BES
  - Test on threshold effect
  - More precise cross section line-shape
  - Complete determination of G_E and G_M



Energy scan in 2014-2015 at BESIII