Baryon form factors at BESIII

Lei Xia (on behalf of BESIII Collaboration)

University of Science and Technology of China, Hefei 230026, Peoples Republic of China
State Key Laboratory of Particle Detection and Electronics, Beijing 100049, Hefei 230026, Peoples Republic of China

16^{th} Conference on Flavor Physics and CP Violation (FCPC 2018)

July 14th 2018, Indian Institute of Technology Hyderabad and University of Hyderabad, Hyderabad, India

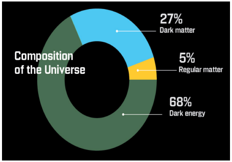
Outline

1. Introduction
2. Accelerator and Detector
3. Measurement of baryon form factors at BESIII
4. Summary

Outline

Preamble

- Baryon mass is the main component of the mass of the universe. It comes from the strong force, not from the Higgs mechanism. (K.Huang, Story of Gauge Fields, 2007, F. Wilczeck, A beautiful question, 2016).



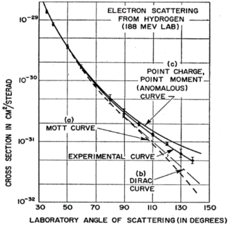
- Baryons, what they really are, is far from being understood.
- Many meson features come from QED to QCD, once $\alpha \rightarrow \alpha_s$. Baryon: no analogue in QED and unique QCD feature.
- For instance:
  - ✓ A fermion with mass, magnetic moment and other parameters close to proton and neutron ones can be obtained as a soliton of a π point-like boson field, by means of a non linear Lagrangian with one free parameter only (**Skyrme model**, Proc. Roy. Soc. **A 260**, (1961), 127)!
  - ✓ The baryon spin is not due to the spins of the valence quarks (**Proton Spin Crisis**, PLB **206**, 364, (1988))!
- Therefore it is meaningful to point out open questions, concerning baryon structure.

Nucleon Electromagnetic Form Factor

- Elastic scattering of electron and proton (Phys. Rev. **98**, 217 R. Hofstadter, Nobel Prize 1961).
  - ✓ Theoretically, differential cross section is:

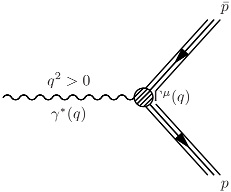
$$(\frac{d\sigma}{d\Omega})_{ep} = (\frac{d\sigma}{d\Omega})_{Mott}(1 + 2\tau tan^2\frac{\theta}{2})F(q^2)$$

  - ✓ The deviation represents the effect of a form factor (FF) for the proton.



- 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:

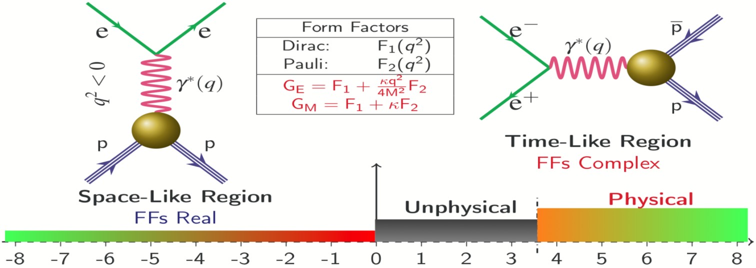
$$ElectronFF : G_E(q^2) = F_1(q^2) + \tau\kappa_p F_2(q^2)$$
$$MagnetFF : G_M(q^2) = F_1(q^2) + \kappa_p F_2(q^2)$$

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

- In the Breit frame: Nucleon spin flip: G_M, non spin flip: G_E

Nucleon Electromagnetic Form Factor

- Measurement of baryon FF: Space-like (SL) and Time-like (TL).

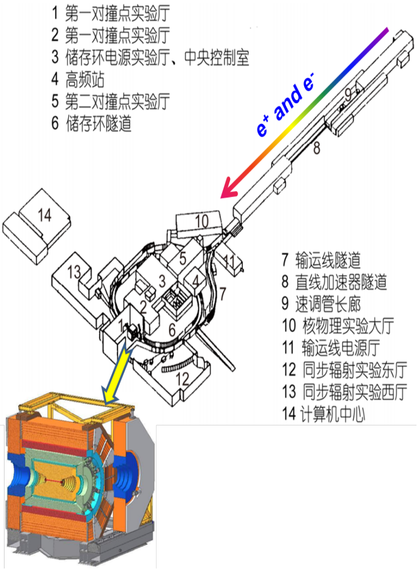


- TL process includes energy scan and initial state radiation (ISR), both techniques can be used at BESIII.

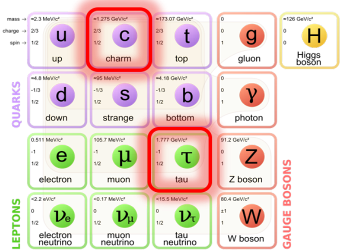
	Energy scan	Initial state radiation
E_{beam}	discrete	fiexd
$\mathcal{L}$	Low at each beam energy	High at one beam energy
σ	$\frac{d\sigma_{p\bar{p}}}{d\cos\theta} = \frac{\pi\alpha^2\beta C}{2q^2}[\lvert G_M\rvert^2(1+\cos^2\theta) + \frac{4m_p^2}{q^2}\lvert G_E\rvert^2\sin^2\theta]$	$\frac{d\sigma_{p\bar{p}\gamma}}{dq^2 d\theta_\gamma} = \frac{1}{s} W(s, x, \theta_\gamma)\sigma_{p\bar{p}}(q^2)$ $\sim \frac{1}{400}$ $W(s, x, \theta_\gamma) = \frac{\alpha}{\pi x}\left(\frac{2-2x+x^2}{\sin^2\theta_\gamma} - \frac{x^2}{2}\right)$
q^2	Single at each beam energy	From threshold to s

Accelerator and Detector

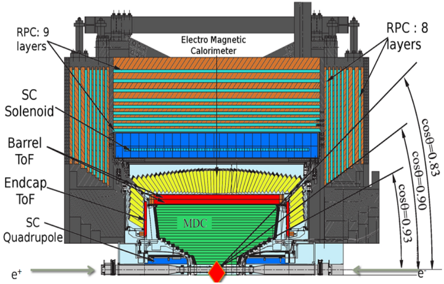
Beijing Electron Positron Collider II



- E_{beam}: 1.0∼2.3 GeV;
- Double storage ring: e^+ and e^-;
- No. of bunches: 93;
- Luminosity: 1.0×10^{33} cm^{-2}s^{-1} @3770MeV



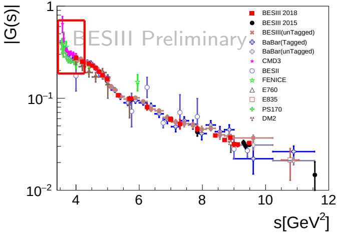
BEijing Spectrometer III

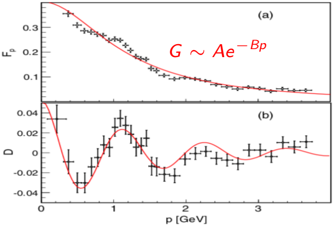


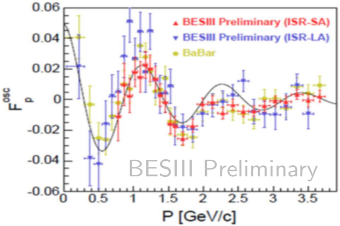
- Main Drift Chamber (MDC): (He/C_3H_8=40/60)
  - σ_{xy}=130μm, dE/dx ~6%;
  - σ_p/p=0.5% at 1 GeV.
- Time Of Flight (TOF): (plastic scintillator)
  - σ_{time}(barrel)=80 ps,
  - σ_{time}(endcap)=110 ps.
- ElectroMagnetic Calorimeter (EMC): (CsI(Tl))
  - σ_E/E(barrel)=2.5% at 1 GeV,
  - σ_E/E(endcap)=5% at 1 GeV.
- Superconducting Magnet: B =1T.
- Muon Counter: Resistive Plate Chambers (RPC):
  - barrel: 9 layers;
  - endcap: 8 layers.
  - $\sigma_{spatial}$=2 cm.

Some unexpected features are proved

- Effective FF ($|G|$) steep drop at threshold: Coulomb Enhancement Factor.
- Oscillations in effective FF ($|G|$) have seen by BaBar and been confirmed by BESIII PRL **114**, 232301 (2015).

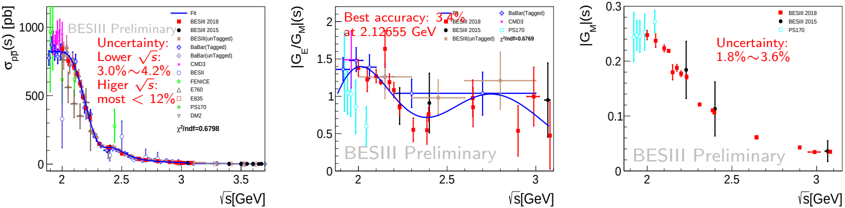






- Plateau above threshold, corresponding to $|G|$ close to 1, like a point-like fermion, similar features is also shown $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$.

Measurement of proton form factor on BESIII



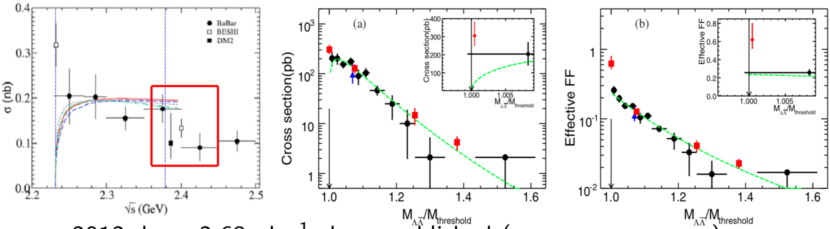
- Energy scan techniques:
  - 2012 data, 156.9 pb^{-1}: have published (PRD **91**, 112004 (2015)).
  - 2015 R-scan data, 688.5 pb^{-1}: under reviewing.
- ISR techniques:
  - Tagged ISR technique 7.4 fb^{-1}: under reviewing.
  - Unagged ISR technique 7.4 fb^{-1}: preliminary results.
- Precision: Greatly improved in 2015 R-scan data!

  σ_{born}: 3.0% $\sim$ 23.5%, |G|: 1.7% $\sim$ 11.8%, $|G_E/G_M|$: $\sim$10% for lower energy points, $|G_M|$: 1.8% $\sim$ 3.6%.

  In TL region, our result is an unprecedented accuracy.

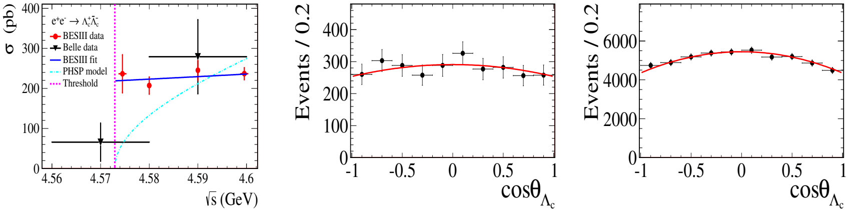
  Especially $|G_E/G_M|$ providing an uncertainty comparable to the SL region for the first time.

Measurement of Λ form factor on BESIII



- 2012 data, 2.63 pb^{-1}: have published (PRD **97**, 032013 (2018)).
  2015 data, 66.9 pb^{-1}: under reviewing.
- The σ_{Born} at 2.2324 GeV is $305\pm45^{+66}_{-36}$ pb, larger than the traditional theory expectation.
- The σ_{Born} at 2.396 GeV is $119.0\pm5.3\pm7.3$ pb, $|G| = 0.123\pm0.003\pm0.004$, $|G_E/G_M| = 0.94\pm0.16\pm0.03\pm0.02(\alpha_\Lambda)$, $\Delta\phi = 42^\circ\pm16^\circ\pm8^\circ\pm6^\circ(\alpha_\Lambda)$.
- The observed threshold enhancement implies a more complicated underlying physics scenario.
- Neutral baryon: no Coulomb, but still jump at threshold!
- Help to understand the mechanism of baryon production and test the theory hypotheses based on the threshold enhancement effect.

Measurement of Λ_c form factor on BESIII



- 2014 data, 631.3 pb^{-1}: have published (PRL **120**, 132001 (2018)).
- The σ_{Born} at 4.5745 GeV is 236$\pm$11$\pm$46 pb, indicates the complexity of production behavior of the Λ_c.
- At threshold, there is indeed a jump in $\sigma_{\Lambda_c^+\bar{\Lambda}_c^-}$.
- Followed by a kind of a plateau.
- At threshold $\sigma_{\Lambda_c^+\bar{\Lambda}_c^-}$ is close to the point-like value, once the Coulomb enhancement factor is taken into account:
  $\sigma_{\Lambda_c^+\bar{\Lambda}_c^-(point-like)} \approx \frac{\pi^2\alpha^3}{2m_{\Lambda_c}} \approx 145$ pb.
- Qualitatively, if $\sigma_{B\bar{B}}$ would be driven by strong interaction, (asymptotically scaling as $(m_p/m_{\Lambda_c})^{10}$) a quite smaller value (<1 fb) would be expected $\sigma_{p\bar{p}} \approx$0.85 nb at threshold.

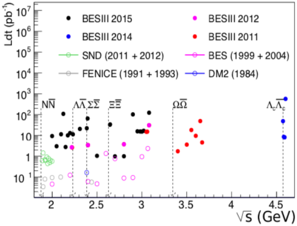
Summary

Summary: Discussion

- Electromagnetic FFs provide a quantitative description of hadron structure and are basic observables of QCD.
- BESIII is unique in its capability to measure baryon FFs, from nucleons to Λ_c and use two complementary approaches: energy scan and ISR technique:
  - Proton FFs have been measured using a test energy scan of 2012 and 2015, for 2012 data have published (PRD **91**, 112004 (2015)), for 2015 data:
    - ✓ Precision greatly improved:
      σ_{born}: 3.0% ∼ 23.5%, $|G|$: 1.7% ∼ 11.8%, $|G_E/G_M|$: ∼10% for lower energy points, $|G_M|$: 1.8% ∼ 3.6%.
    - ✓ In TL region, our result is an unprecedented accuracy.
    - ✓ Especially $|G_E/G_M|$ providing an uncertainty comparable to the SL region for the first time.
  - Very exciting results from tagged ISR on protons expected very soon, preliminary results on untagged ISR techniques.
  - Published results on σ and FFs from Λ (PRD **97**, 032013 (2018)) and Λ_c (PRL **120**, 132001 (2018)) close to threshold.
    - ✓ Preliminary results on Λ at 2.396 GeV.

Summary: Future

- Near future:
  - Present theory is missing something.
  - Proton: more data from CMD3 and BESIII.
  - Λ and ϕK^+K^-: more data around $\Lambda\bar{\Lambda}$ threshold.
  - Λ_c: more data at threshold and above by BESIII.



  - Neutron: more data from SND, CMD3. Publication by BESIII.
  - $Br(J/\psi \to \gamma n\bar{n})$: Publication by BESIII.
  - G_E/G_M phase: more data from BESIII.
- Far future:
  - Super τ/charm: in Russia (Novosibirsk?) or China (Hefei?, Beijing?, CEPC booster?).

Thanks all for hard work!

Thanks for your attention!