Measurements of hadron electromagnetic structure at BESIII

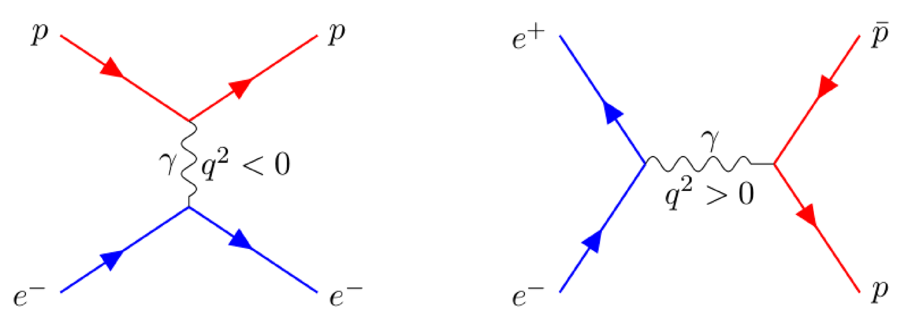
Cui Li, on behalf of the BESIII collaboration
Department of Physics and Astronomy, Uppsala University
cui.li@physics.uu.se

Form Factors: Why?

- Electromagnetic form factors(FFs) provide fundamental information about the internal electromagnetic structure of hadrons.
- Form Factors are fundamental observables of QCD and each non-pQCD model (Chiral perturbation theory, Lattice QCD, Vector Meson Dominance...) give predictions of FFs as output.
- The structure of light baryons is very difficult, but very important, to understand.
  - For nucleons, FFs give complementary information to Generalized Parton Distributions(GPDs) about the structure.
  - For hyperons, FFs is the only experimentally feasible way to study the structure.
  - Comparing hyperon FFs with nucleon FFs provide a powerful test of SU(3) flavour symmetry of the strong interaction.

Space/Time-like FFs

- Proton FFs can be measured in space-like(SL) and time-like(TL) region.
- Most of previous experimental data are in the former, while the measurement in the later are scarce and with large errors.



- Feynman diagram of $ep \to ep$ elastic scattering at the lowest order(left). The momentum transfer squared, q^2, is negative and the FFs are real functions of q^2.
- Feynman diagram of $e^+e^- \to p\bar{p}$ annihilation at the lowest order(right). Here, q^2 is positive and the FFs are complex functions of q^2.

Form factors in the time-like region

- Differential cross section of $e^+e^- \to p\bar{p}$ can be written as a function of FFs, electric $|G_E|$ and magnetic $|G_M|$:
$\frac{d\sigma}{d\Omega} = \frac{\alpha^2\beta C}{4q^2}[|G_M(q^2)|^2(1+cos^2\theta) + \frac{1}{\tau}|G_E(q^2)|^2(sin^2\theta)]$
- Born cross section: $\sigma(q^2) = \frac{4\alpha^2\beta C}{3q^2}[|G_M(q^2)|^2 + \frac{1}{2\tau}|G_E(q^2)|]$
- Effective FFs: $|G(q^2)| = \sqrt{\frac{\sigma}{\frac{4\pi\alpha^2\beta C}{3q^2}(1+\frac{1}{2\tau})}}$ with assumption of $|G_M(q^2)| = |G_E(q^2)| = |G(q^2)|$.

- θ polar angle of the proton in the e^+e^- c.m. system.
- q^2 transferred momentum
- $\tau = q^2/(4m_p^2)$

- α fine structure constant
- β velocity of p
- $C = 1$ coulomb correction

In experiment: $\sigma_{Born} = \frac{N_{signal}}{L\epsilon(1+\delta)}$, where N_{signal} is the number of signal events, L is the integrated luminosity, ϵ is the detection efficiency and the 1+δ is the radiative correction factor.

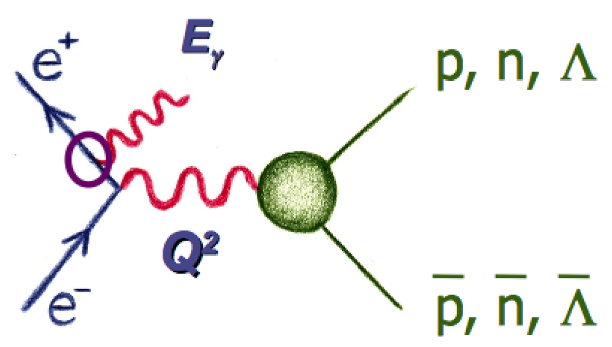
Extract Electromagnetic $R = |G_E/G_M|$ ratio:

- Angular dependence: $\frac{d\sigma}{dcos\theta} = N_1[(1+cos^2\theta) + \frac{R^2}{\tau}(1-cos^2\theta)]$, N_1 is the overall normalization.

All the formulas are valid for the baryons with spin=$1/2$.

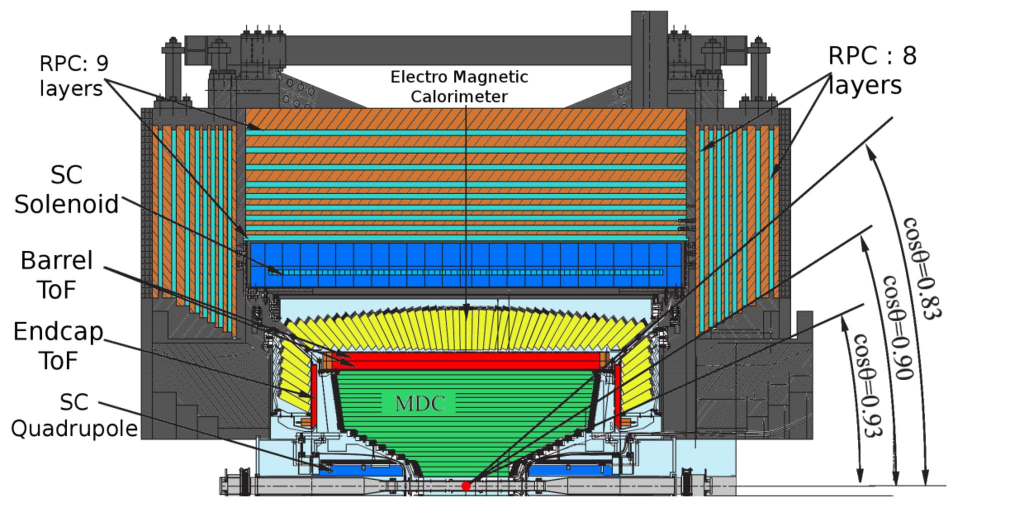
Experimental measurement of time-like form factors

- In the direct production channel $e^+e^- \to p\bar{p}$ (scan method), scanning over several, off-resonance CMS energies.
- In the radiative return channel $e^+e^- \to p\bar{p}(\gamma_{ISR})$, where γ_{ISR} refers to a photon emitted by initial-state radiation (the Radiative Return[1]). Data at a fixed energy collider with high luminosity could be used.



The BESIII experiment at BEPCII

- BEPCII is a double-ring e^+e^- collider running at c.m. energies between 2.0-4.6GeV and reaching a peak luminosity of 0.85×10^{33}cm^{-2}s^{-1} at a c.m. energy of 3.770GeV.
- The cylindrical BESIII detector has an effective geometrical acceptance of 93% of 4π and is divided into a barrel section and two end caps.

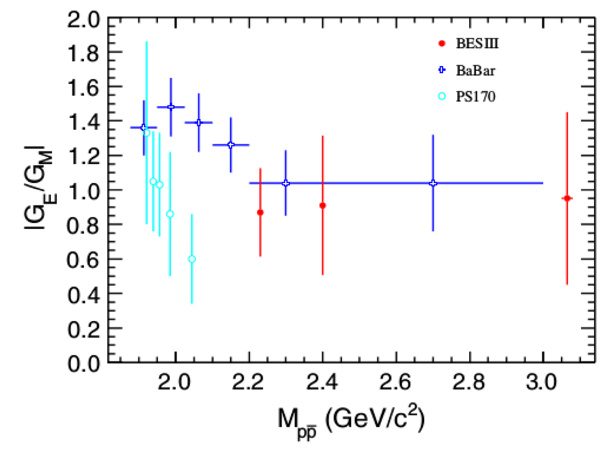


[1] Phys. Lett. B 459, 279(1999)
[2] Phys. Rev. D 91, 112004(2015)

Results of proton time-like form factors[2]

- Data samples at 12 cms energies from 2232.4 to 3671.0 MeV.
- Scan method are used with those data samples.

$\sqrt{s}$ (MeV)	$\lvert G_E/G_M \rvert$	$\lvert G_M \rvert$ ($\times10^{-2}$)	χ^2/ndf
		Fit on $\cos\theta_p$	
2232.4	$0.87 \pm 0.24 \pm 0.05$	$18.42 \pm 5.09 \pm 0.98$	1.04
2400.0	$0.91 \pm 0.38 \pm 0.12$	$11.30 \pm 4.73 \pm 1.53$	0.74
(3050.0, 3080.0)	$0.95 \pm 0.45 \pm 0.21$	$3.61 \pm 1.71 \pm 0.82$	0.61
		Method of moments	
2232.4	0.83 ± 0.24	18.60 ± 5.38	···
2400.0	0.85 ± 0.37	11.52 ± 5.01	···
(3050.0, 3080.0)	0.88 ± 0.46	3.34 ± 1.72	···

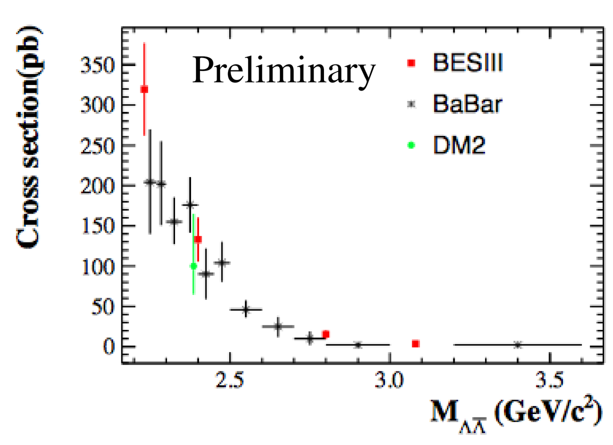


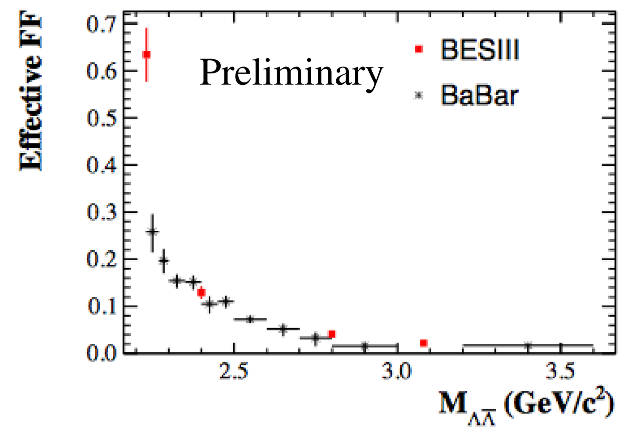
- The proton effective FFs are measured at 12 c.m. energies.
- The Born cross sections and effective FFs are in good agreement with previous experiments, improving the overall uncertainty by 30%.
- $|G_E/G_M|$ ratio are extracted at three energy points, with uncertainty in 25% and 50% (dominated by statistics).
- $|G_E/G_M|$ ratio are close to unity and consistent with BaBar results in the same q^2 region, indicates the data are consistent with the assumption $|G_E| = |G_M|$ within uncertainties.

The new scan data at 2015 will provide more precise data on the ratio and the effective FFs.

Results of Λ time-like form factors

- Data sets collected at 2.2324 GeV, 2.40 GeV, 2.80 GeV and 3.08 GeV
- The same scan method used to $e^+e^- \to p\bar{p}$.





- Surprisingly, large cross section near threshold! The data points from BESIII give an important contribution to world data.
- Data sample is too small to extract angular distributions.
- The coming scan data will provide precise measurements on ratio and effective FFs.

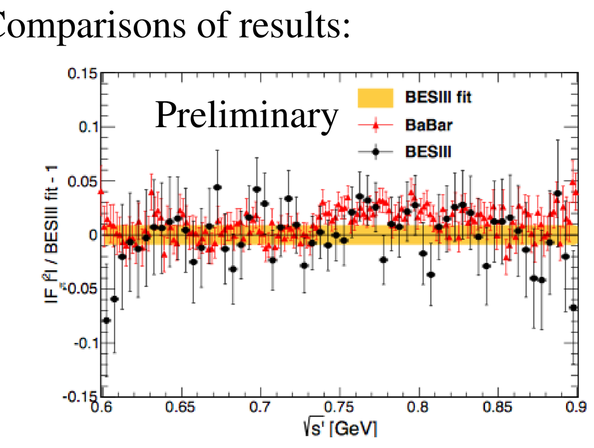
The anomalous magnetic moment of the muon a_μ

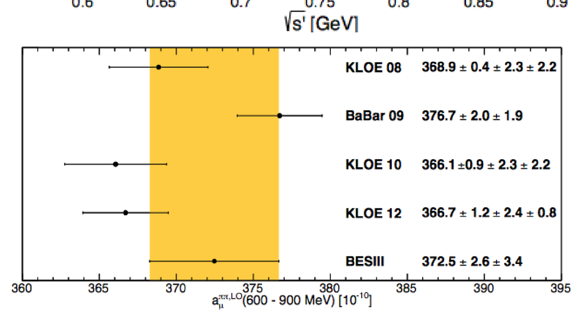
- $a_\mu \equiv (g-2)_\mu/2$, a famous precision observable of the standard model(SM).
- It's accuracy is entirely limited by the knowledge of the hadronic vacuum polarization contribution, which is obtained in a dispersive framework by using experimental data on $\sigma(e^+e^- \to hadrons)$.
- The cross section $\sigma_{\pi\pi}$ contributes to more than 70% to this dispersion relation.
- Currently, a discrepancy of 3.6 standard deviations is found between the direct measurement of a_μ and its SM prediction.

Measurement of the $e^+e^- \to \pi^+\pi^-$

- Data at a cms energy $\sqrt{s}$ =3.773GeV
- Signal process $e^+e^- \to \pi^+\pi^-\gamma$
  - photon emitted in the initial state
  - nominal energy lowered by the energy of the emitted photon
  - measurements at different energies possible (600-900MeV)
- A deviation of more than 3σ between the SM prediction of a_μ and its direct measurement is confirmed.
- Currently a systematic uncertainty of 1.3% is reached.
- We want to redo the luminosity measurement to decrease this error.

Comparisons of results:





Outlook

New scan data at c.m. energy from 2.0 GeV to 3.1 GeV is coming:

- improve precision measurement of proton form factor, $|G_E/G_M|$ ratio uncertainty
- measurement of neutron form factor is ongoing
- to measure Hyperons(Λ, Σ) TL FFs
  - measure effective FFs, $|G_E/G_M|$ ratio and Λ polarization
  - in the time-like region, the Ffs are complex numbers, i.e. G_E and G_M have a relative phase
  - the phase has polarisation effects even if the initial state is unpolarised
  - thanks to the self-analysing decay of hyperons, the polarisation and thus the phase is accessible for hyperons
  - the Uppsala group is responsible