Recent results of Baryon electromagnetic form factors at BESIII

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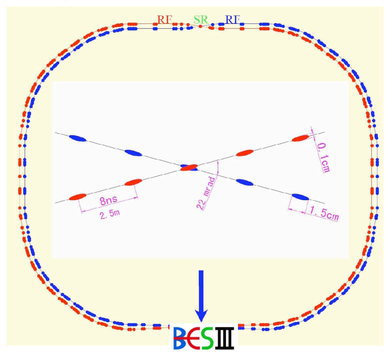
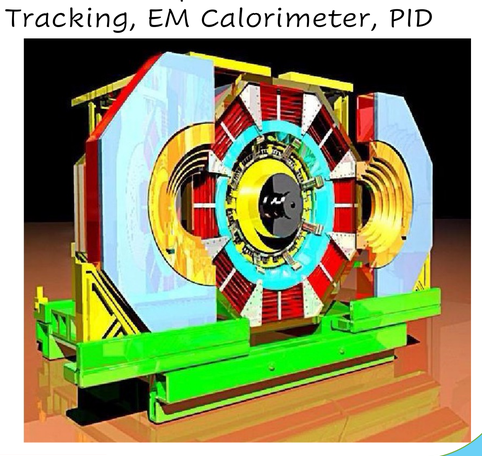
Intro to BESIII @BEPCII

Double ring electron-positron collider
CMS energy range 2.00 – 4.95 GeV
Reached design luminosity @ψ(3770)=10^{33} cm^{-2} s^{-1}

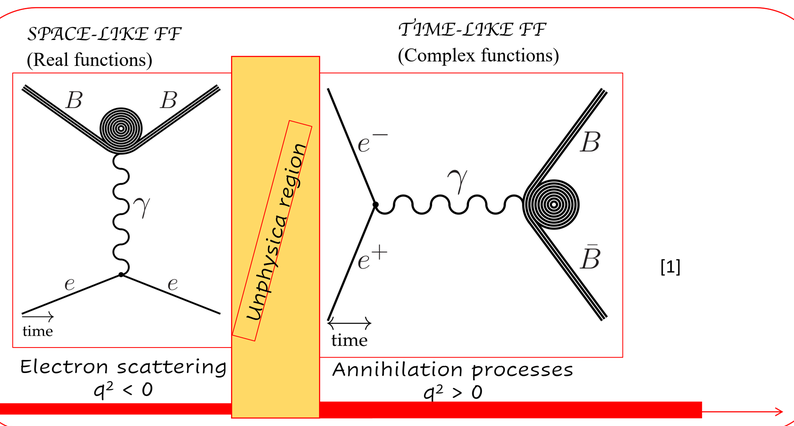


BEijing Spectrometer:
93% 4π acceptance
Tracking, EM Calorimeter, PID



Intro to form factors

Form factors (FFs) parametrize electromagnetic hadronic currents in Born approximation.
A spin-S hadron has 2s+1 independent from factors.



[1]

For spin ½ Baryons

Sachs parameterization:

$$G_E(q^2) = F_1(q^2) + \frac{q^2}{4M_B}F_2(q^2)$$

Electric FF

$$G_M(q^2) = F_1(q^2) + F_2(q^2)$$

Magnetic FF

F_1, Dirac FF and F_2, Pauli FF

Time-like form factors

Related to space-like FFs *via* dispersion relations.
From total cross section→ effective FF
Ratio $R_{EM} = |G_E/G_M|$ accessible from baryon scattering angle.
$\Delta\Phi(q^2) = \Phi_E(q^2) - \Phi_M(q^2)$ = relative phase between G_E and G_M
→ Polarises final state!

How to access experimentally in BESIII?

Direct Scan:
Fixed q^2, single data point @ each beam energy
Relatively low integrated luminosity @ each data point

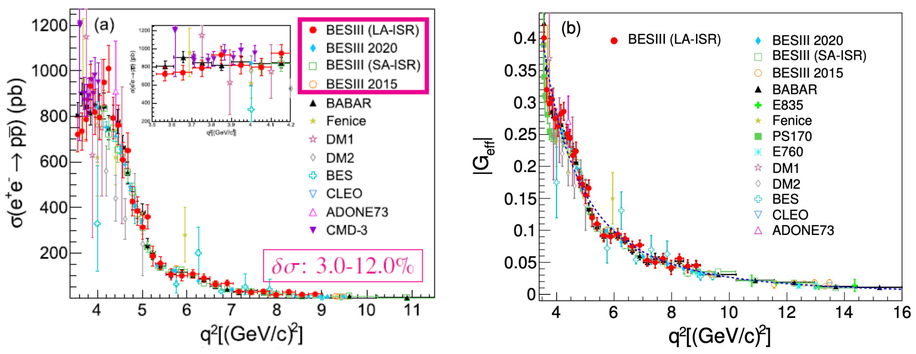
$$\frac{d\sigma^{Born,1\gamma}}{d\Omega} = \frac{\alpha^2\beta C}{4q^2}[(1+\cos^2\theta)|G_M|^2 + \frac{4M^2}{q^2}\sin^2\theta|G_E|^2$$

ISR:
continuous q^2, from threshold to s
Relatively high integrated luminosity @one beam energy $x = 1 - q^2/s = 2E_\gamma/\sqrt{s}$

$$\frac{d\sigma^{ISR}}{dx d\theta_\gamma} = W(s,x,\theta_\gamma)\sigma^{Born}(q^2)$$

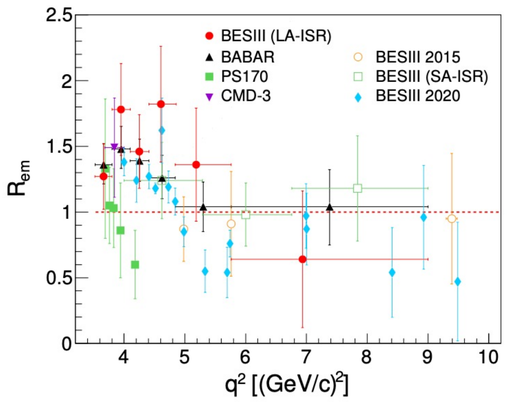
$$W^{LO}(s,x,\theta_\gamma) = \frac{\alpha}{\pi x}\left(\frac{2-2x+x^2}{\sin^2\theta_\gamma} - \frac{x^2}{2}\right)$$

Proton form factors



Scan Method →most accurate measurement of cross section from 2.00–3.08 GeV (22 points)[2]
ISR Method allows wider range → Small Angle ISR up to 3.8 GeV [3]
Large Angle ISR down to the threshold [4]

Modified dipole function well describes the data [5]



$\mathcal{R}_{EM}$ from the study of scattering angle ($\cos\theta_p$) distribution, with high accuracy, with uncertainty comparable to data in space-like experiments .

First measurement of $|G_E|$ (and $|G_M|$)in time-like region in wide range

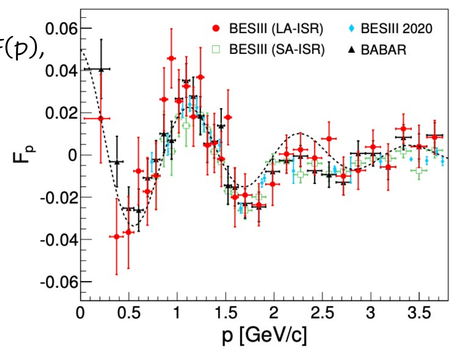
Nucleons'FSI as explanation of the steep deviation from 1

Oscillating behaviour observed in reduced form factor F(p), as function of relative momentum of p and pbar

$$F_p = b_0^{osc} e^{-b_1^{osc}p}\cos(b_2^{osc}p + b_3^{osc}),$$

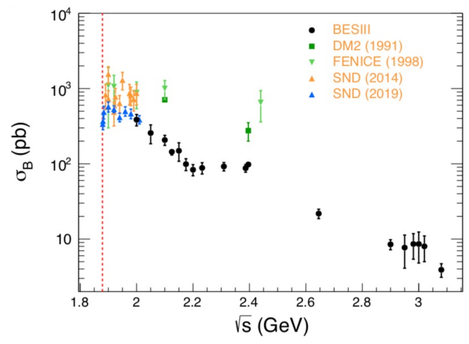
Modified dipole function, [5]
that reproduces effective FF behaviour

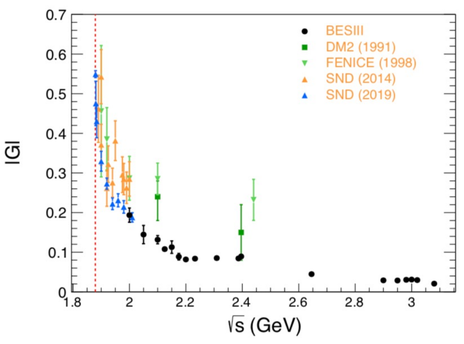
$$|G_{eff}(s)| = \frac{\mathcal{A}}{(1+\frac{s}{m_a^2})[1-\frac{s}{0.71(\mathrm{GeV}/c)^2}]^2},$$



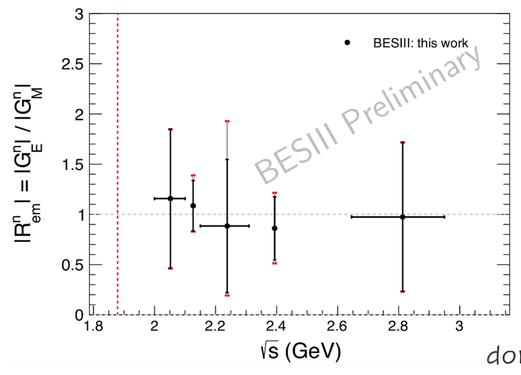
Neutron form factors

Challenging and long waited measurement! [6]





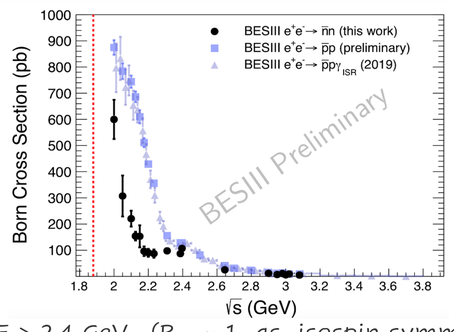
$$\sigma_{Born} = \frac{N_{data}}{\epsilon_{n\bar{n}}^{MC}\times\mathcal{C}_{dm}\times\mathcal{C}_{trg}\times(1+\delta)\times\mathcal{L}_{Int}} \qquad |G_{eff}| = \left(\frac{3q^2}{4\pi\alpha^2\beta(1+\frac{2m_n^2}{q^2})}\right)^{\frac{1}{2}}\sqrt{\sigma_{Born}}$$

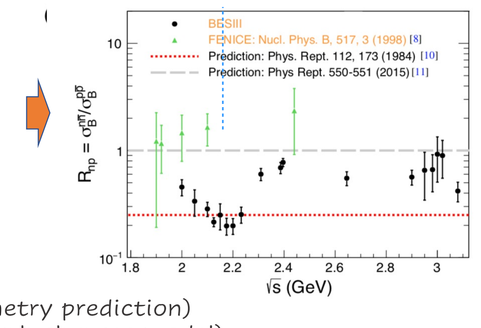


$$\frac{d\sigma_B}{d\cos\theta} = \frac{\pi\alpha^2\beta}{2q^2}|G_M|^2\left[(1+\cos^2\theta) + \frac{1}{\tau}|R_{em}|^2\sin^2\theta\right]$$

FIRST measurement from angular distribution in time-like region!

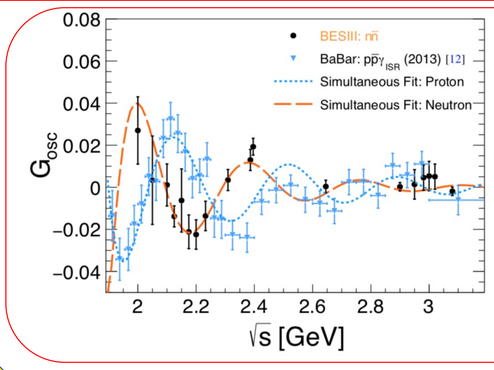
dominated by statistical uncertainties





E > 2.4 GeV (R_{np} ~ 1 as isospin symmetry prediction)
E < 2.4 GeV (R_{np}~ $|q_d/q_u|^2$ ~ 0.25 as quark charges model)

photon-proton stronger than the corresponding photon-neutron interaction

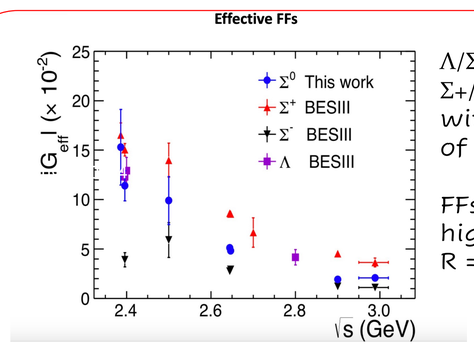


Simultaneous fit of proton and neutron data, shared frequency with a relative phase shift of ~125° ±12°to that for the proton.

$$G_{osc} = A\cdot\exp(-B|p|)\cdot\cos(C_{shared}|p| + D)$$

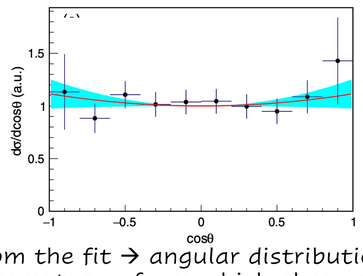
Other Baryons (selected results)

Study the $e\,e \to BB$, where $B = \Lambda, \Sigma, \Xi, \Lambda c$



Λ/Σ effective FFs similar as expected [7][8][9]
Σ+/ Σ- cross section ratio ~ 9** , in disagreement with the expected SU(3) symmetry breaking of 10-30% .[8]

FFs ratio of the Σ^+ determined at three high-statistics energy points by angular distribution.
R =1.83±0.26 @ 2.396 GeV



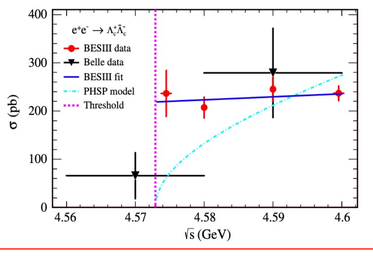
First complete measurement of Λ FF @2.396 GeV[10]

$R = |G_E/G_M| = 0.96 \pm 0.14 \pm 0.02$
$\Delta\Phi = 37^o \pm 12^o \pm 6^o$
$\sigma = 118.7 \pm 5.3 \pm 5.1$ pb

From the fit → angular distribution parameter -> from which phase and R

First direct measurement of Λ_c FFs. [11]
Ratio $|G_E/G_M|$ of Λ_c FFs measured for the first time at √s = 4.5745 GeV and √s = 4.5995 GeV

$\sqrt{s}$ MeV	$\lvert G_E/G_M\rvert$
4574.5	$1.10 \pm 0.14 \pm 0.07$
4599.5	$1.23 \pm 0.06 \pm 0.03$



- The BESIII experiment provides an ideal environment to measure the Baryon FFs.
- Hadron structure is a tool to understand the strong interaction.
- Time-like form factors are the easiest structure observables.
- A step further towards unified view of the scattering and annihilation regions (phenomenological VMD and dispersion relations).
- STAY TUNED for further results with more data.

References

[1] Bertani, M et al. Symmetry (2022,) *14*, 439
[2] BESIII, Phys.Rev.Lett. 124 (2020) 4, 042001
[3] BESIII, Phys. Rev. D 99 (9) (2019) 092002
[4] BESIII, Phys.Lett.B 817 (2021) 136328
[5] Tomasi-Gustavson *et al* ,Phys. Lett. B 504, (2001)291
[6] BESIII, Nature Phys. 17 (2021) 11, 1200-1204
[7] BESIII, Phys. Rev. D 97, (2018) 032013
[8] BESIII, Phys. Lett. B, 814,(2021) 136110
[9] BESIII, Phys.Lett.*B* 831 (2022) 137187
[10] BESIII, Phys. Rev. Lett. 123, (2019) 122003
[11] BESIII, Phys. Rev. Lett. 120, (2018), 132001