The 22nd International Spin Symposium (SPIN2016)

Baryon Electromagnetic Form Factors at BESIII

Dexu Lin

Helmholtz-Institut Mainz, Germany
Institut für Kernphysik, JGU Mainz, Germay

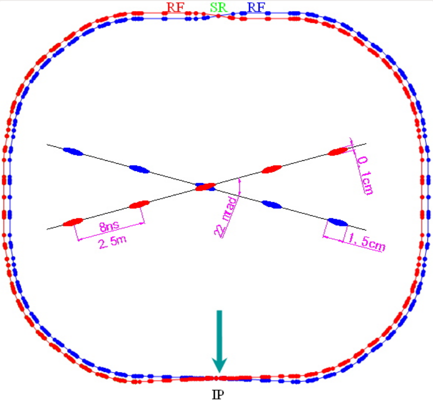
(On Behalf of BESIII Collaboration)

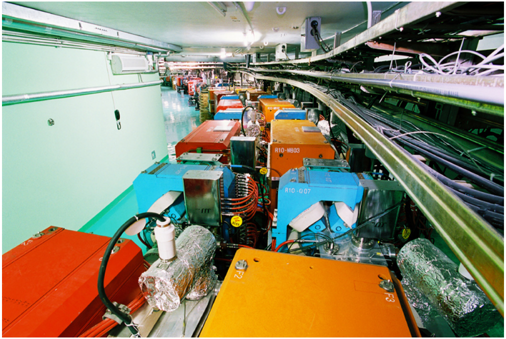
UIUC, IL, USA
Sep. 25 - 30, 2016

Outline

BEPCII and BESIII

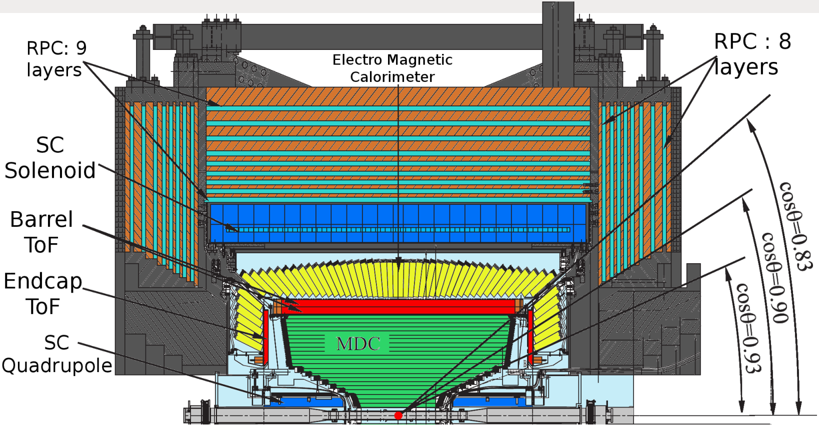
Double Storage Rings of BEPCII: A τ-charm factory





Beam energy:	1.0 - 2.3 GeV	Beam current:	0.91 A
Optimum energy:	1.89 GeV	Designed Lumi:	1×10^{33} cm^{-2}s^{-1}
Crossing Angle:	$\pm$11 mrad	Achieved time:	5th April, 2016

BESIII Spectrometer



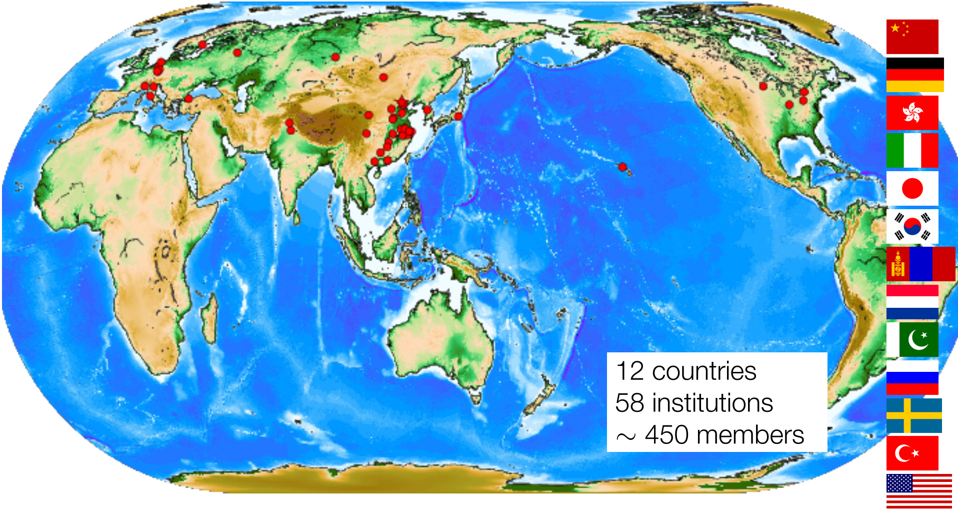
MDC
$\frac{\delta p}{p} < 0.5\%$ @1 GeV
$\frac{\delta(dE/dx)}{dE/dx} < 6\%$

TOF
δt 80 ps Barrel
δt 110 ps Endcap

EMC
$\frac{\delta E}{E} < 2.5\%$ @1 GeV
$\delta z = 0.6/\sqrt{E}$

MUC
$\delta(xy)$ <2 cm

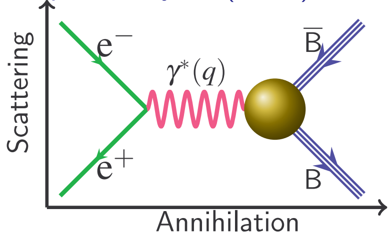
The BESIII Collaboration



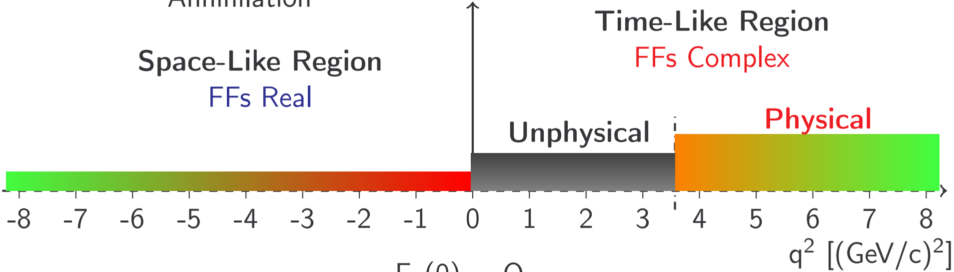
Electromagnetic (EM) Form Factors (FFs)

❀ Spin s Baryon: $(2s+1)$ EM FFs

✿ $\Gamma^{\mu} = F_1(q^2)\gamma^{\mu} + \frac{i\kappa}{M} F_2(q^2)\sigma^{\mu\nu} q_{\nu}$



Form Factors	
Dirac:	$F_1(q^2)$
Pauli:	$F_2(q^2)$
$G_E = F_1 + \frac{\kappa q^2}{4M^2} F_2$	
$G_M = F_1 + \kappa F_2$	

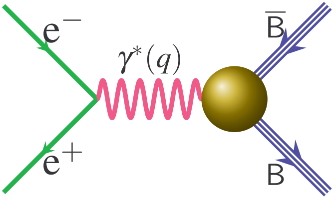


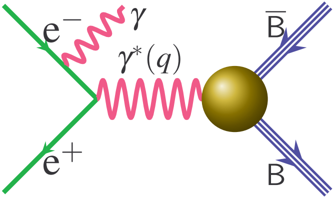
$|G_{E,M}(-\infty)| = |G_{E,M}(+\infty)|$

$F_1(0) = Q$
$F_2(0) = 1$

$|G_E(4M^2)| = |G_M(4M^2)|$

FFs Measurements in Time-Like Region





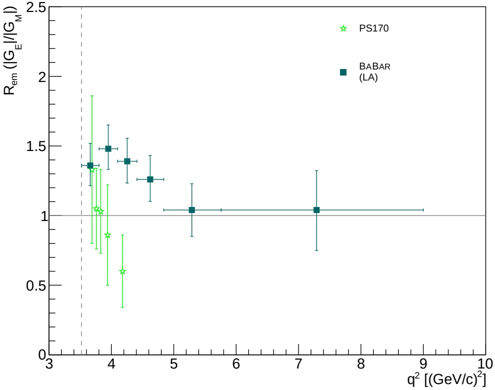
$x \equiv 2E_\gamma/\sqrt{s}$

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

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

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

The Status of Proton FFs in TL Region (Ratio)



$M_{p\bar{p}}$, GeV/c^2	N	N_{bkg}	$\lvert G_E/G_M \rvert$
1.877–1.950	1162	19 ± 10	$1.36^{+0.15+0.05}_{-0.14-0.04}$
1.950–2.025	1290	53 ± 16	$1.48^{+0.16+0.06}_{-0.14-0.05}$
2.025–2.100	1328	63 ± 14	$1.39^{+0.15+0.07}_{-0.14-0.07}$
2.100–2.200	1444	118 ± 28	$1.26^{+0.14+0.10}_{-0.13-0.09}$
2.200–2.400	1160	126 ± 26	$1.04^{+0.16+0.10}_{-0.16-0.10}$
2.400–3.000	879	122 ± 22	$1.04^{+0.24+0.15}_{-0.25-0.15}$

⇒ Only extraction of the ratio $\frac{|G_E|}{|G_M|}$,

⇒ **Inconsistency** between BaBar and PS170,

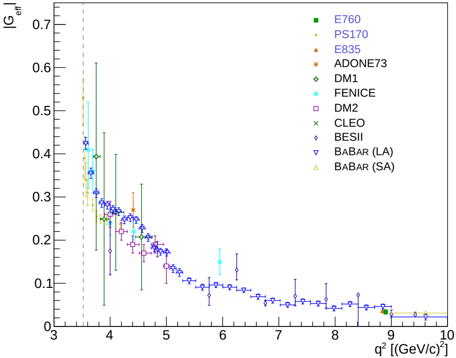
⇒ Maximum at 2 GeV/c^2,

⇒ Extraction of an effective FF based on assumptions,

⇒ 10%–24% statistics uncertainties.

PRD 87, 092005 (2013)
Nucl. Phys. B 411, 3 (1994)
(Until 2013)

The Status of Proton FFs in TL Region (Effective FF)



Effective FFs of proton

$$e^+e^- \to p\bar{p}$$

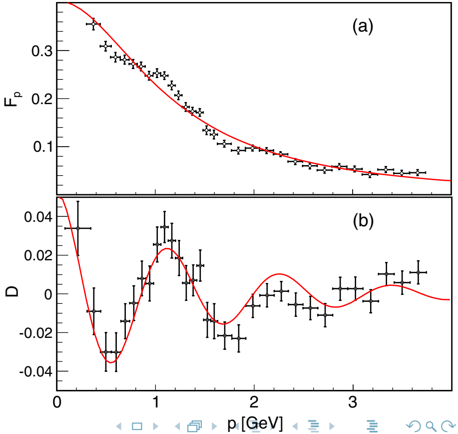
$$\sigma = \frac{4\pi\alpha^2\beta C}{3q^2}\left(|G_M|^2 + \frac{1}{2\tau}|G_E|^2\right)$$

$$|G_{eff}| = \sqrt{\frac{3q^2}{4\pi\alpha^2\beta C}\frac{\sigma}{(1+\frac{1}{2\tau})}}$$

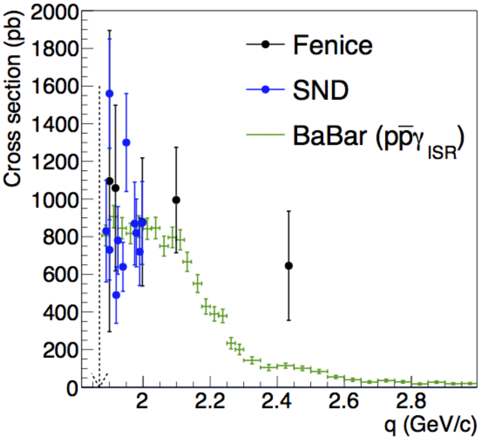
Oscillation behavior of Eff. FF from BABAR data

Rescattering in final state?

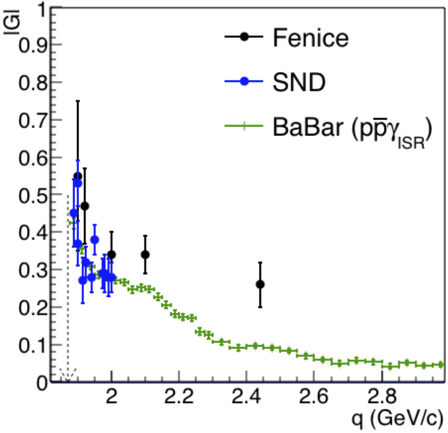
(PRL **114**, 232301 (2015))



The Status of Neutron FFs in TL Region (Effective FF)

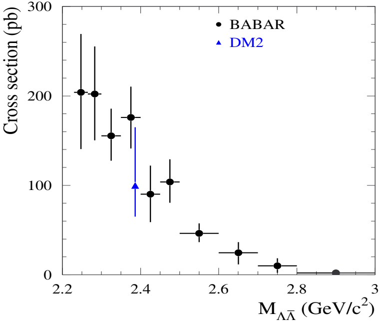


- ➢ $|G^n_{eff}|$ larger than proton,
- ➢ No individual FFs (or ratio).

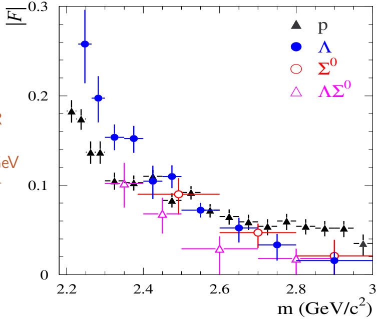


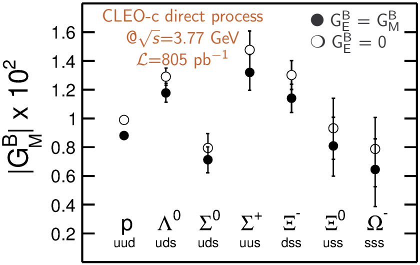
- ➢ Two direct measurements,
- ➢ Non-zero cross section at threshold,
- ➢ Flat in low range ($\sigma_n \sim \sigma_p$).

The Status of Hyperons FFs in TL Region



BABAR ISR process
@$\sqrt{s}$=10.58 GeV
$\mathcal{L}$=232 fb^{-1}

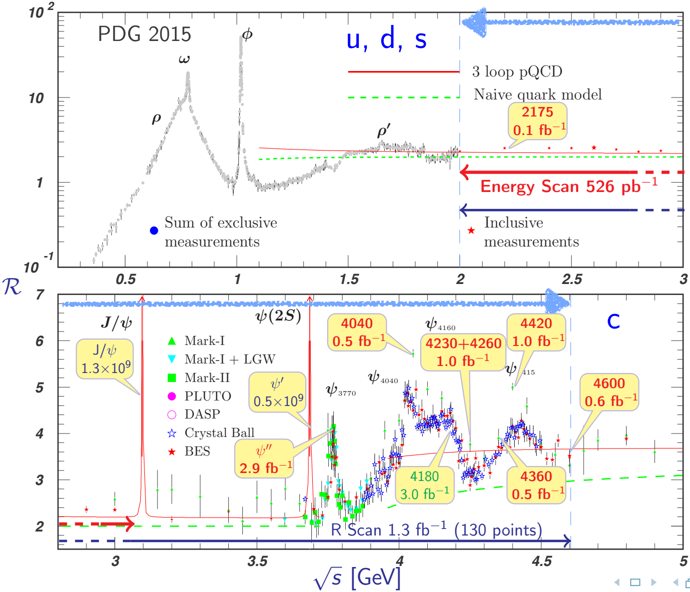


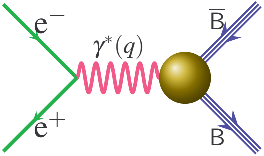


- Only experimentally accessible in TL region
- Scarce data by CLEO-c, BABAR and DM2
- Effective FF seems larger than for protons

Nucl. Phys. **B** 225-227 (2012) 205
Phys. Lett. **B** 739 (2014) 90

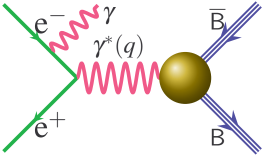
BESIII Data Samples





Baryon FFs from energy scan data by $e^+e^- \to B\overline{B}$

Baryon FFs from data by $e^+e^- \to B\overline{B}\gamma_{ISR}$ ($\mathcal{L}_{int}(\geq \psi'')$: 7.4 fb^{-1})



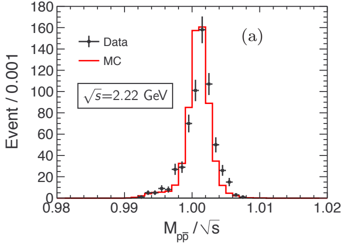
Proton FFs from Scan Data 2012

PRD91. (2015) 112004

R-scan data: 157 pb^{-1} in 12 points collected between 2.22 to 3.67 in 2011/2012.

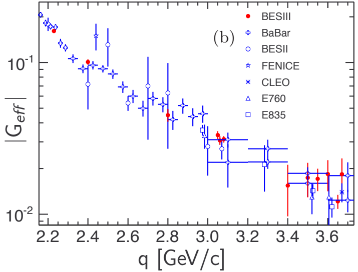
➢ **Event selection** of $e^+e^- \to p\bar{p}$:

- Two charged tracks from the vertex,
- PID as proton or antiproton,
- Kinematics constraints apllied,
- Background negligible or subtracted.



➢ **Cross section** and **effective FF**

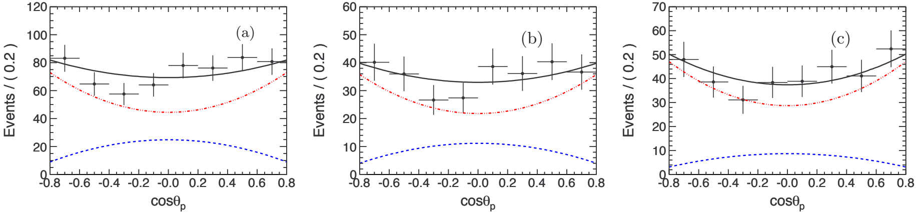
- Born cross section: $\sigma^{Born} = \frac{N^{obs} - N^{bkg}}{\epsilon(1+\delta)\mathcal{L}}$
- Effective FF: $G_{eff} = \sqrt{\frac{3q^2}{4\pi\alpha^2\beta C} \cdot \frac{\sigma^{Born}}{1+1/2\tau}}$
- Good agreement with previous ones,
- The precision improved.

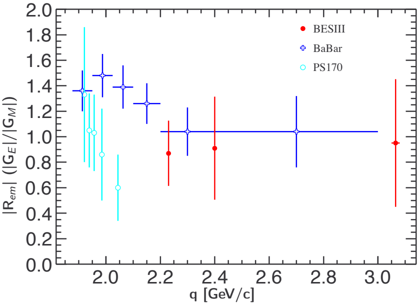


Ratio of Proton FFs from Scan Data 2012

PRD91. (2015) 112004

Extraction of the **Ratio**: $\frac{d\sigma}{dcos\theta} = \mathcal{N}_{norm}[(1 + cos^2\theta) + |R^2_{em}|(1 - cos^2\theta)]$

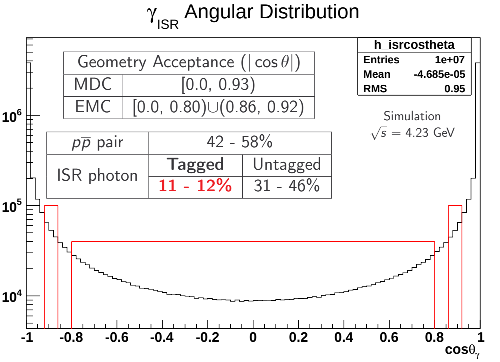


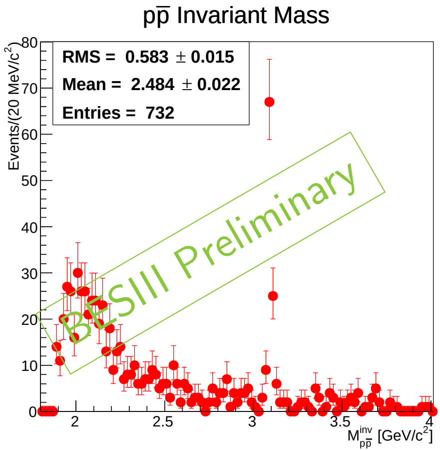


$\sqrt{s}$ (MeV)	$\|G_E/G_M\|$	$\|G_M\|$ ($\times 10^{-2}$)	χ^2/ndf
	Fit on $\cos\theta_p$		
2232.4	$0.87 \pm 0.24 \pm 0.05$	$18.42 \pm 5.09 \pm 0.98$	1.04
2400.0	$0.91 \pm 0.38 \pm 0.12$	$11.30 \pm 4.73 \pm 1.53$	0.74
(3050.0, 3080.0)	$0.95 \pm 0.45 \pm 0.21$	$3.61 \pm 1.71 \pm 0.82$	0.61

- $|G_E|$ and $|G_M|$ extracted individually
- Precision between 11% and 28%
- Consistent with previous one at same q-range

ISR-Tagged Analysis for Proton



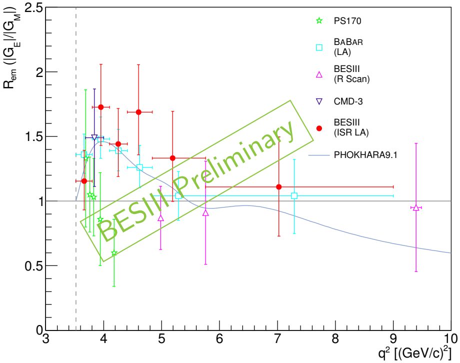


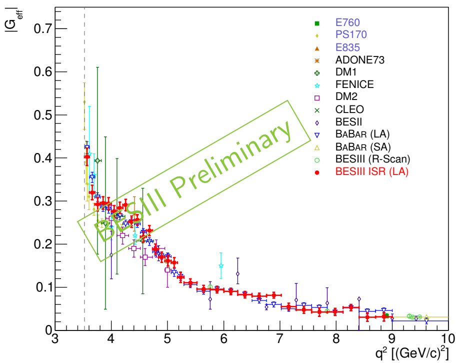
- 7 data samples ($\geq$ 3.773 GeV)
- Total luminosity 7.4 fb^{-1}
- Event selction:
  - Two charged tracks from vertex
  - One high energy shower in EMC
  - Kinematic constraints applied
- Background evaluation and subtraction

Data at the energy 4.23 GeV

$p\bar{p}$ invariant mass spectrum from threshold

Preliminary Results from ISR-Tagged Analysis





- Background subtraction and efficiency correcting
- Combine the seven data samples
- The proton FFs extracted between th. – 3.0 GeV
- Systematic uncertainty included

	$\delta R_{em}/R_{em}$	$\delta G_{eff}/G_{eff}$
stat.	16% - 34%	5% - 32%
syst.	4% - 8%	2% - 12%

LA: **L**arge polar **A**ngle of ISR photon
SA: **S**mall polar **A**ngle of ISR photon

Lambda FFs from Scan Data 2012

Two channels for 2.2324 GeV:

- Charged channel: $\bar{\Lambda} \to \bar{p}\pi^+$, $\Lambda \to p\pi^-$ pion pairs and annihilation from $\bar{p}$
- Neutral channel: $\bar{\Lambda} \to \bar{n}\pi^0$, X π^0 reconstructed and $\bar{n}$ shower

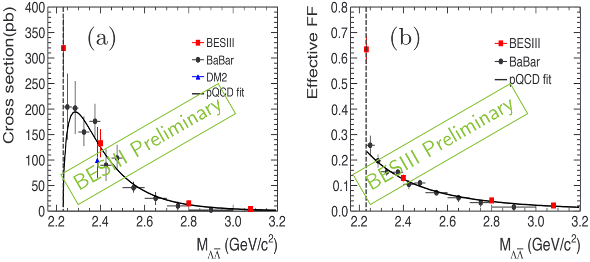
Only charged channel for other data:

- Full reconstruction for 4 tracks
- Kinematic constraints applied

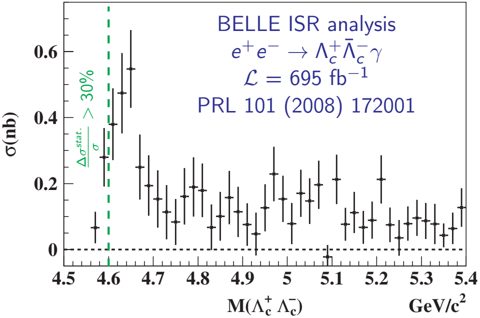
$\sqrt{s}$ GeV	Reconstruction	σ_{Born} (pb)	$\lvert G\rvert$ ($\times 10^{-2}$)
2.2324	$\Lambda \to p\pi^-$, $\bar{\Lambda} \to \bar{p}\pi^+$	325 ± 53 ± 46	
	$\bar{\Lambda} \to \bar{n}\pi^0$	(3.0 ± 1.0 ± 0.4) × 10^2	
	combined	320 ± 58	63.4 ± 5.7
2.40		133 ± 20 ± 19	12.93 ± 0.97 ± 0.92
2.80		15.3 ± 5.4 ± 2.0	4.16 ± 0.73 ± 0.27
3.08		3.9 ± 1.1 ± 0.5	2.21 ± 0.31 ± 0.14

$$\sigma = \frac{4\pi\alpha^2\beta}{3q^2}\left[1 + \frac{1}{2\tau}\right]\left|G_{eff}(q^2)\right|^2$$

- ➢ Preliminary results for Λ
- ➢ Non-zero behavior at threshold
- ➢ Precision improved by 10%



Measurement of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ at BESIII



Data samples collected closing to Λ_c^+ threshold by BESIII in 2014

$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb^{-1})
4.5745	**47.67**
4.580	8.545
4.590	8.162
4.5995	**566.9**

- **First measurement** of FFs ratio for charmed hyperon: very high statistical accuracy,
- Cross section measurement at four energy points with unprecedented statistical accuracy,
- Line-shape study for the charmed hyperons pair production closing to the threshold.

Prospects of the Baryon FFs at BESIII

- Proton FFs:
  - Energy scan between 2.0 – 3.08 GeV.
  - High precision $|G_M|$ and $|G_E|$ (R_{em}) extraction individually.
  - More data at high energy resonances for both ISR **tagged** and **untagged** analysis.
- Neutron FFs:
  - **Extract $|G_M|$ and $|G_E|$ (R_{em}) first time** from energy scan.
  - ISR-tagged analysis for neutron effective FF from threshold.
- Hyperon FFs:
  - Full determination of Λ FFs and polarization.
  - Other hyperon channels including Σ^0, $\Sigma^\pm$, Ξ^0, Ξ^- and Ω^-.
  - Charmed hyperon Λ_c^+ at threshold.

Summary

- Excellent laboratory for baryon form factors measurements at BESIII: energy scan and initial state radiation.
- **Proton form factors** have been extracted with a fraction of scan data (2012).
- Preliminary results on **Proton form factors** from ISR-tagged analysis with the data at resonances (≥ 3.773 GeV).
- Preliminary results on Λ with a fraction of scan data (2012) at threshold.
- The measurements of **baryon form factor** will be significantly improved with the energy scan data from 2.0 GeV to 3.08 GeV

Summary

- Excellent laboratory for baryon form factors measurements at BESIII: energy scan and initial state radiation.
- **Proton form factors** have been extracted with a fraction of scan data (2012).
- Preliminary results on **Proton form factors** from ISR-tagged analysis with the data at resonances ($\geq$ 3.773 GeV).
- Preliminary results on Λ with a fraction of scan data (2012) at threshold.
- The measurements of **baryon form factor** will be significantly improved with the energy scan data from 2.0 GeV to 3.08 GeV