Baryon form factor measurement at BESIII

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on behalf of BESIII Collaboration

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Outline

- Motivation
- Definition of baryon form factors (FFs)
- BESIII detector
- Status of baryon FFs measurements
  - Proton FFs
  - Neutron FFs
  - Hyperon FFs
- Summary

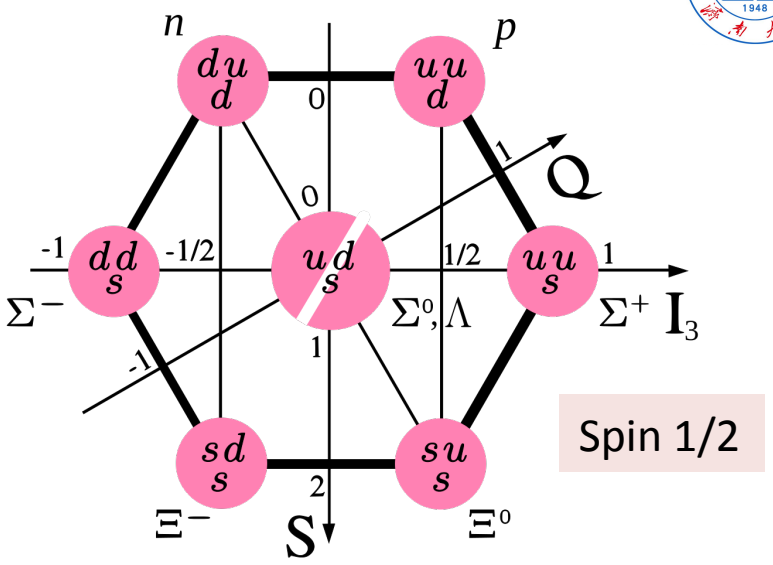
Motivation

1

Baryons have structure

Understanding baryons' structure **helps understand QCD**

FFs describe baryons' internal structure



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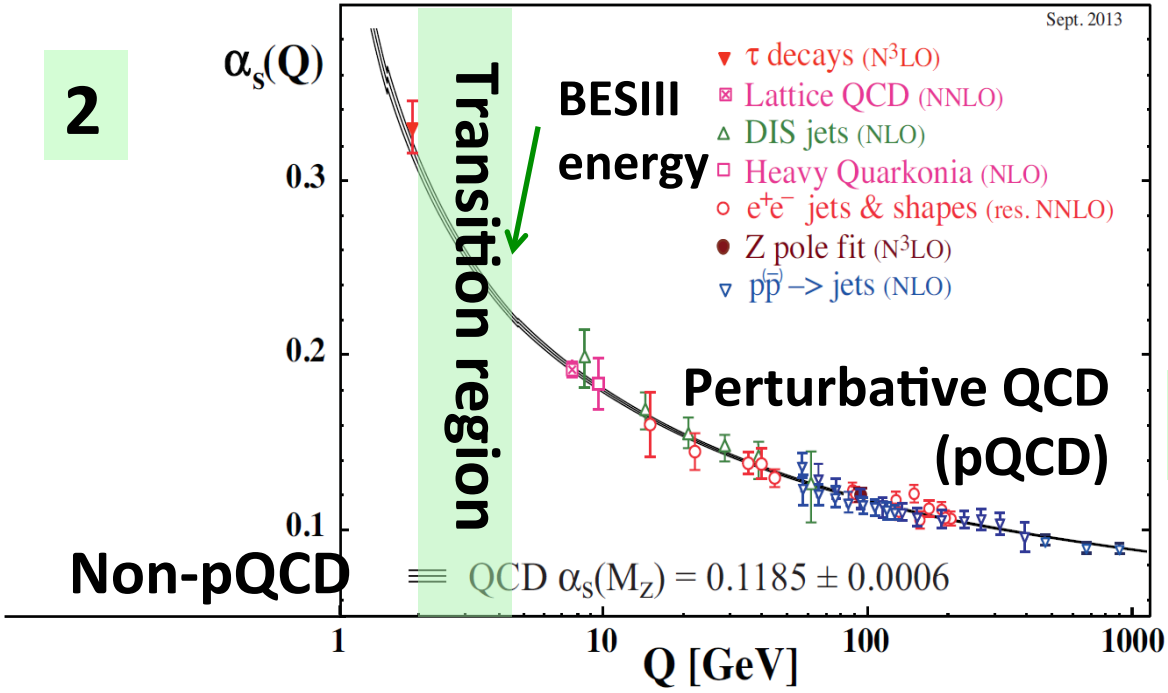

FFs help understand strong interaction

Inputs to QCD models

Outline

- Motivation
- Definition of baryon form factors (FFs)
  - Dirac and Pauli FFs, Electromagnetic (**EM**) FFs, **ratio** of EM FFs, effective (**EF**) FFs
- BESIII detector
- Status of baryon FFs measurements
  - Proton FFs
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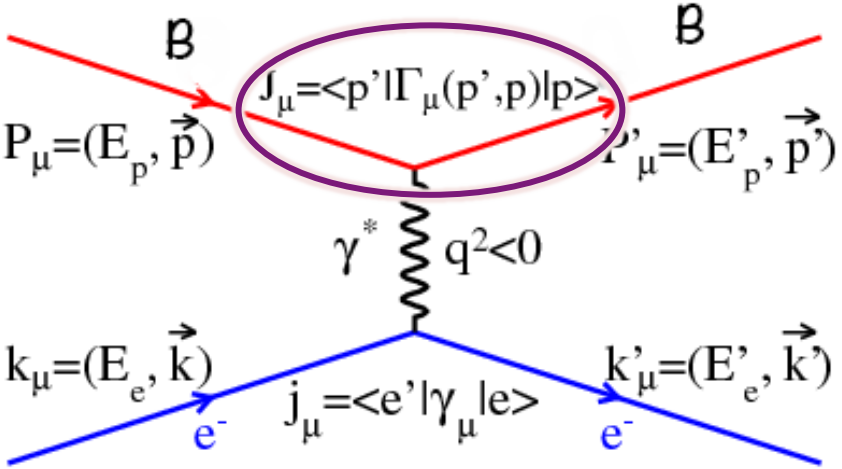
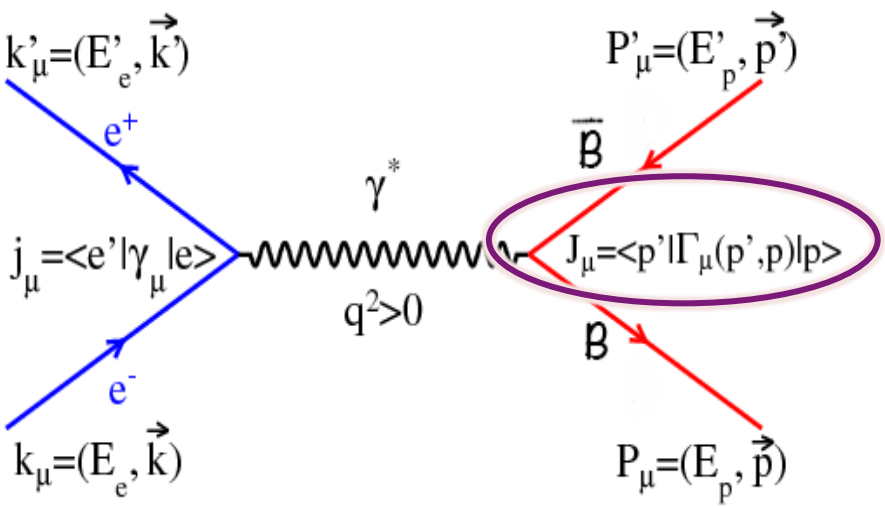
Dirac FF and Pauli FF





Elastic scattering:

Space-like (SL) region, $q^2 < 0$

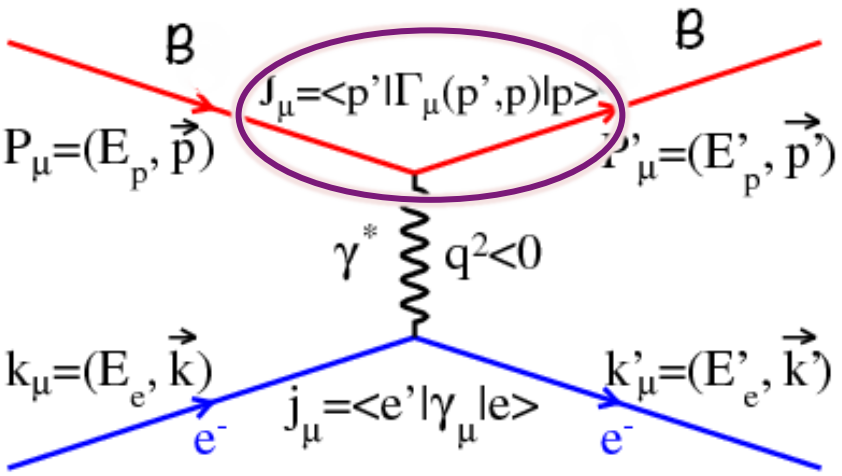
Annihilation:

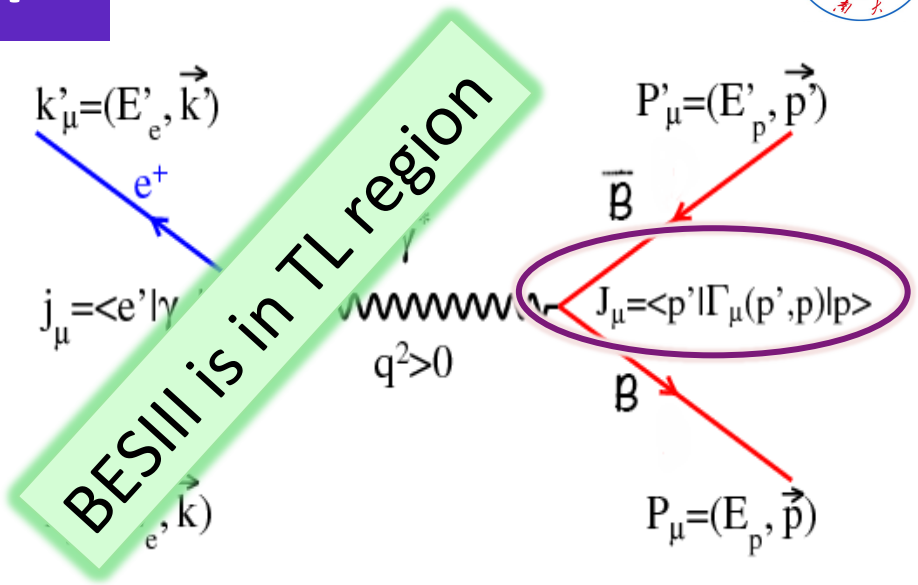
Time-like (TL) region, $q^2 > 0$

Baryon vertex: $$\Gamma_\mu = \gamma^\mu F_1\left(q^2\right) + \frac{i\sigma^{\mu\nu}q_\nu}{2M_B}\kappa F_2\left(q^2\right)$$

$F_1\left(q^2\right)$: Dirac FF, $F_2\left(q^2\right)$: Pauli FF

Dirac FF and Pauli FF





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$F_1(q^2)$: Dirac FF, $F_2(q^2)$: Pauli FF

EM FFs and TL angular distribution

EM FFs:

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

Electric

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

Magnetic

How to measure them? → Angular analysis

TL:

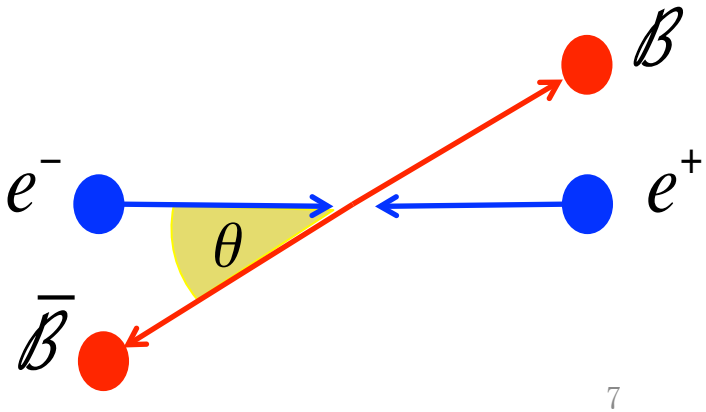
$$\frac{d\sigma_{born}}{d\Omega} = \frac{\alpha^2\beta\zeta}{4q^2}\left[\frac{1}{\tau}\sin^2\theta|G_E|^2 + (1+\cos^2\theta)|G_M|^2\right]$$

$\beta = \sqrt{1-1/\tau}$

ζ : Coulomb correction

function of q^2 and θ:

- q^2: 4-momentum transferred by the virtual photon
- θ: polar angle of baryon in CM (center-of-mass system)



Ratio of EM FFs and effective FFs

Angular distribution written as function of EM FFs ratio:

$$\frac{d\sigma_{born}}{d\Omega} = \frac{\alpha^2\beta\zeta}{4q^2}\left|G_M\left(q^2\right)\right|\left[\left(1+\cos^2\theta\right)+R_{EM}^2\frac{1}{\tau}\sin^2\theta\right]$$

Ratio of EM FFs:

$$R_{EM} = \left|G_E\left(q^2\right)/G_M\left(q^2\right)\right|$$

Born cross section:

$$\sigma_{born} = \frac{4\pi\alpha^2\beta\zeta}{3q^2}\left[\left|G_M\right|^2+\frac{1}{2\tau}\left|G_E\right|^2\right]$$

Assume: $|G| = |G_E| = |G_M|$

EF FFs:

$$\left|G\left(q^2\right)\right| = \sqrt{\sigma_{born}\Big/\left[\frac{4\pi\alpha^2\beta\zeta}{3q^2}\left(1+\frac{1}{2\tau}\right)\right]}$$

Above baryon threshold: ζ=1

All formula valid for spin 1/2

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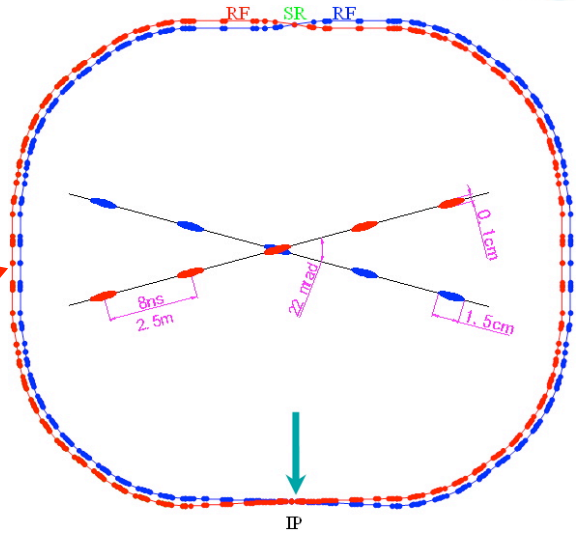
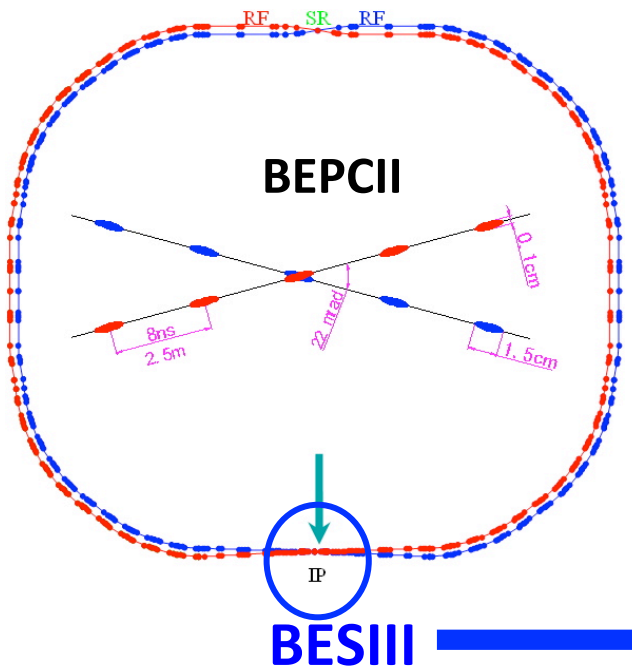
BEPCII

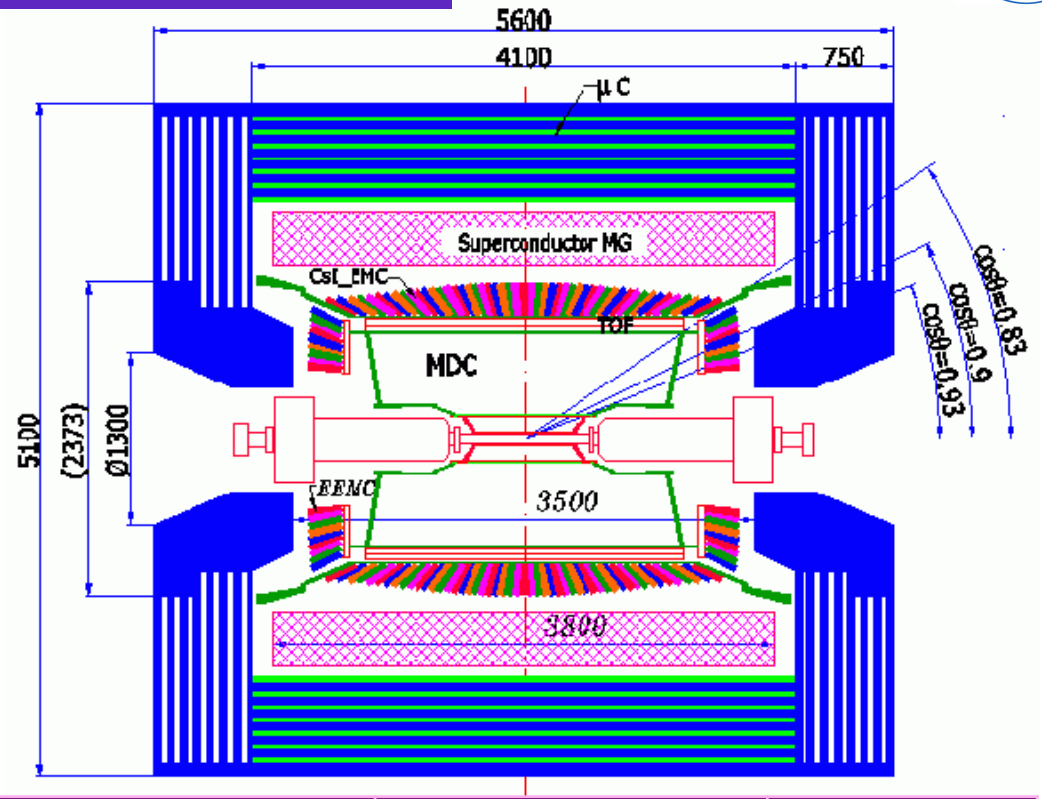


- Runs started in 2009
- CM energy:
  2.0 – 4.6 GeV
- "τ-charm factory"

- Peak instantaneous luminosity:
  - 1×10^{33} $cm^{-2}s^{-1}$ (designed)
  - **1×10^{33} $cm^{-2}s^{-1}$ (achieved)**
- Energy spread: 5.16×10^{-4} GeV

BESIII detector at BEPCII





	MDC	TOF	EMC	MUC
Sub-detectors	Main Drift Chamber	Time of Flight	Electromagnetic Calorimeter	Muon Counter
Resolution	115μm(wire), < 5% (dE/dx)	68ps (Barrel), 100ps (Endcap)	2.3% (energy)	

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    - e^+e^-→ppbar process
    - ISR (Initial State Radiation) process
  - Neutron FFs
  - Hyperon FFs
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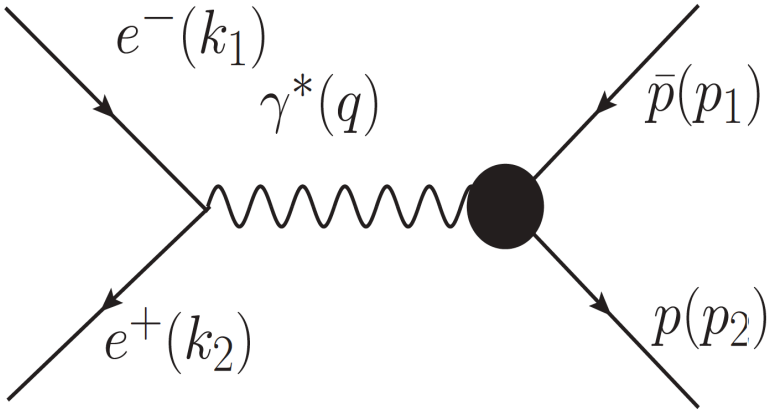
Proton FFs in $e^+e^-\rightarrow p\bar{p}$



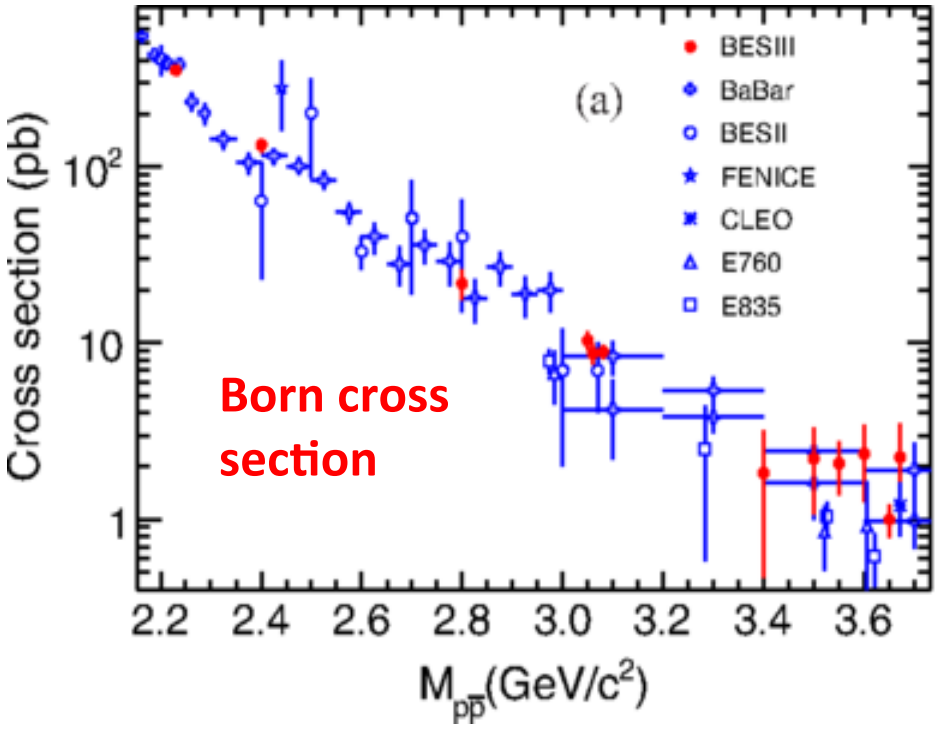
Energy scan method

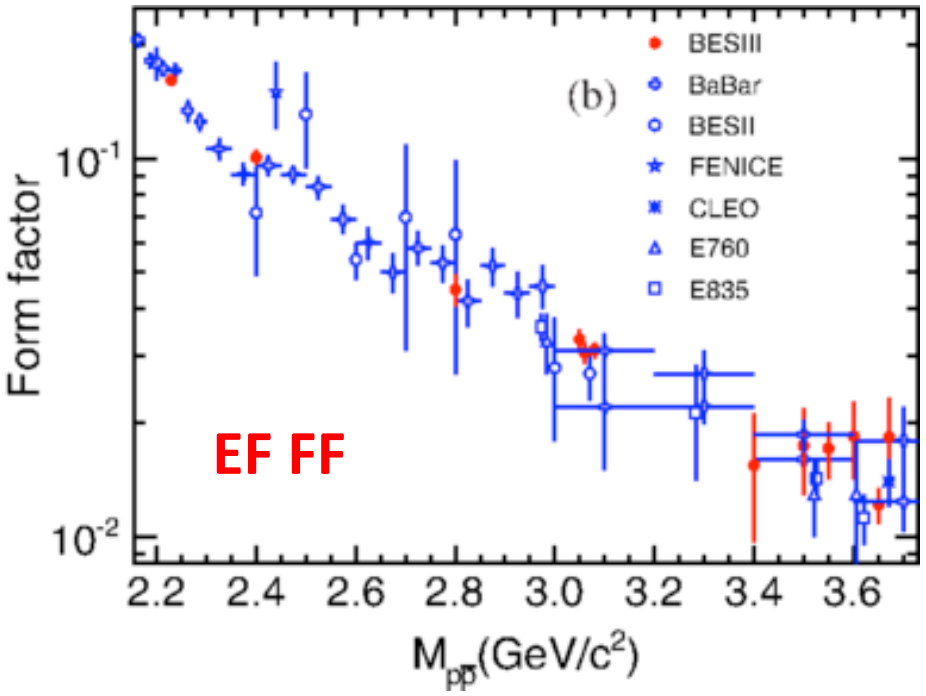
Proton FFs at BESIII in $e^+e^-\rightarrow p\bar{p}$ bar

Phys. Rev. D 91, 112004 (2015)

Born cross section at **12** CM energies from 2.2324 to 3.671 GeV, integrated luminosity 156.94 pb^{-1}, scanned in 2011 and 2012

EF FFs at **12** CM energy points





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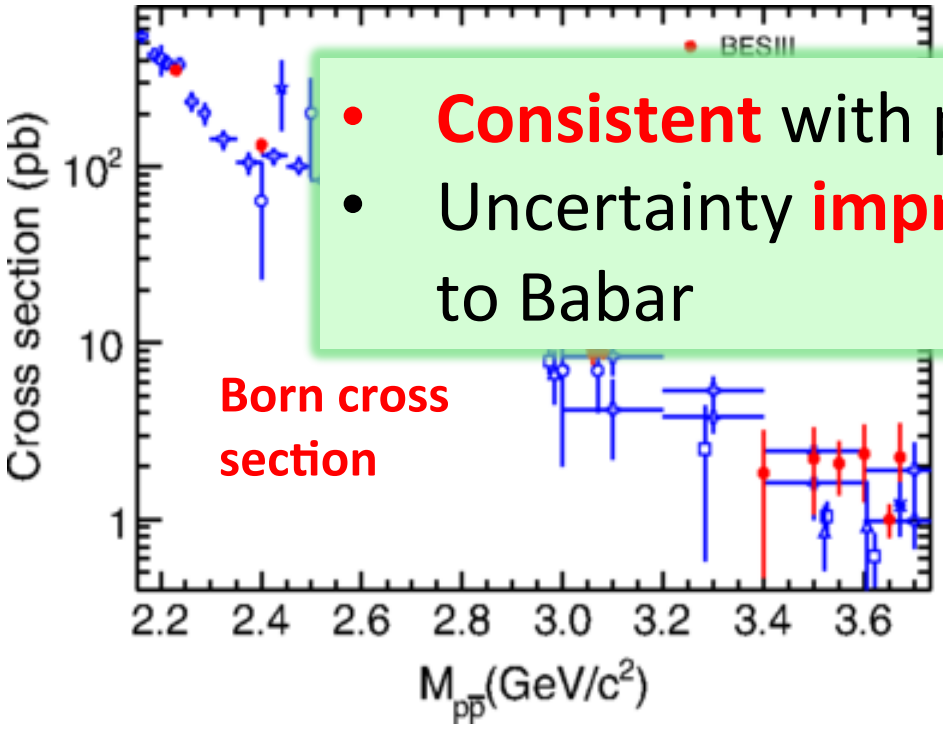
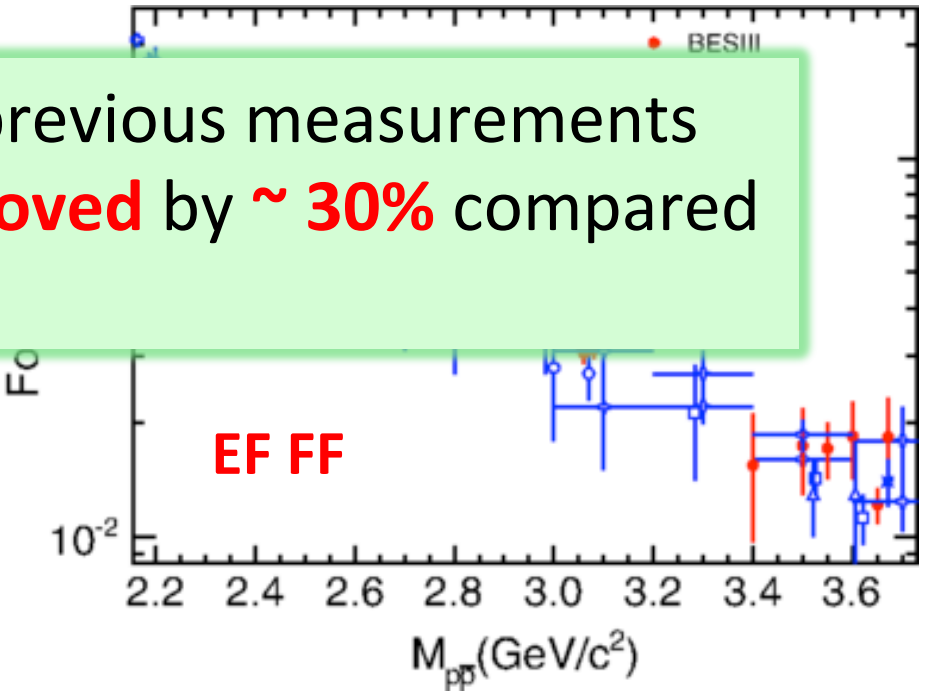


Born cross section

- **Consistent** with previous measurements
- Uncertainty **improved** by **~ 30%** compared to Babar

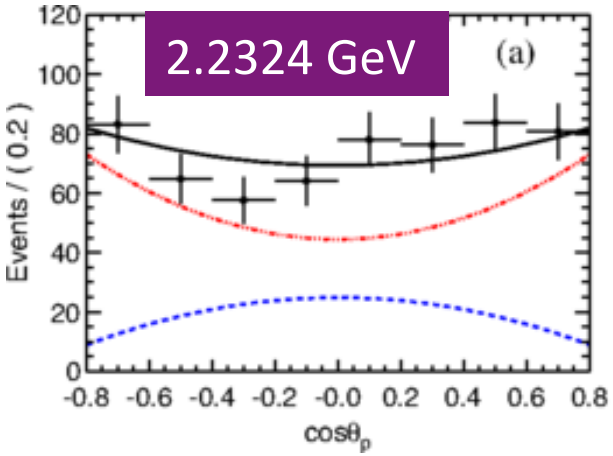


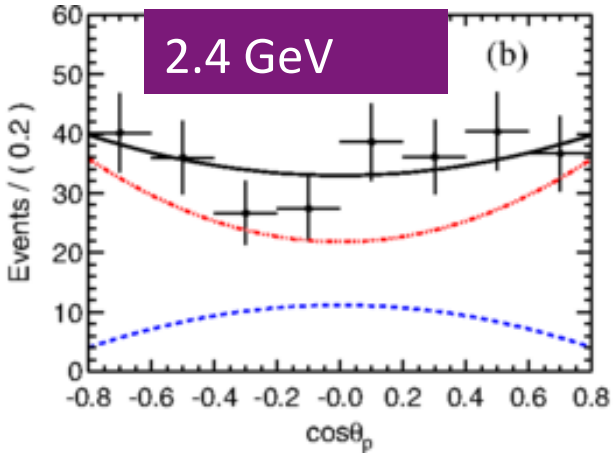
EF FF

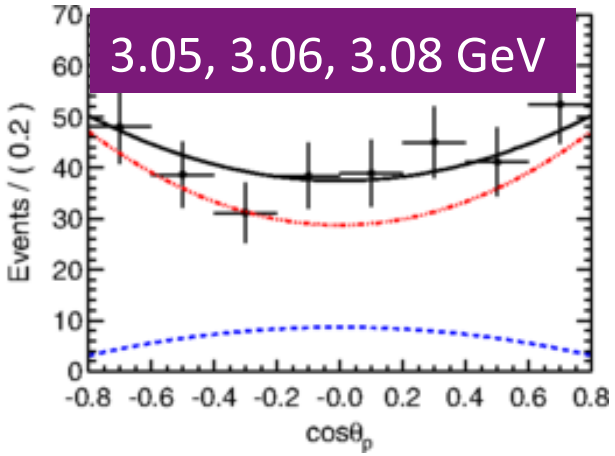
Proton FFs at BESIII in e^+e^-→ppbar

Phys. Rev. D 91, 112004 (2015)

R_{EM} at **3** points: 2.2324, 2.4, combined 3.05, 3.06 and 3.08 GeV





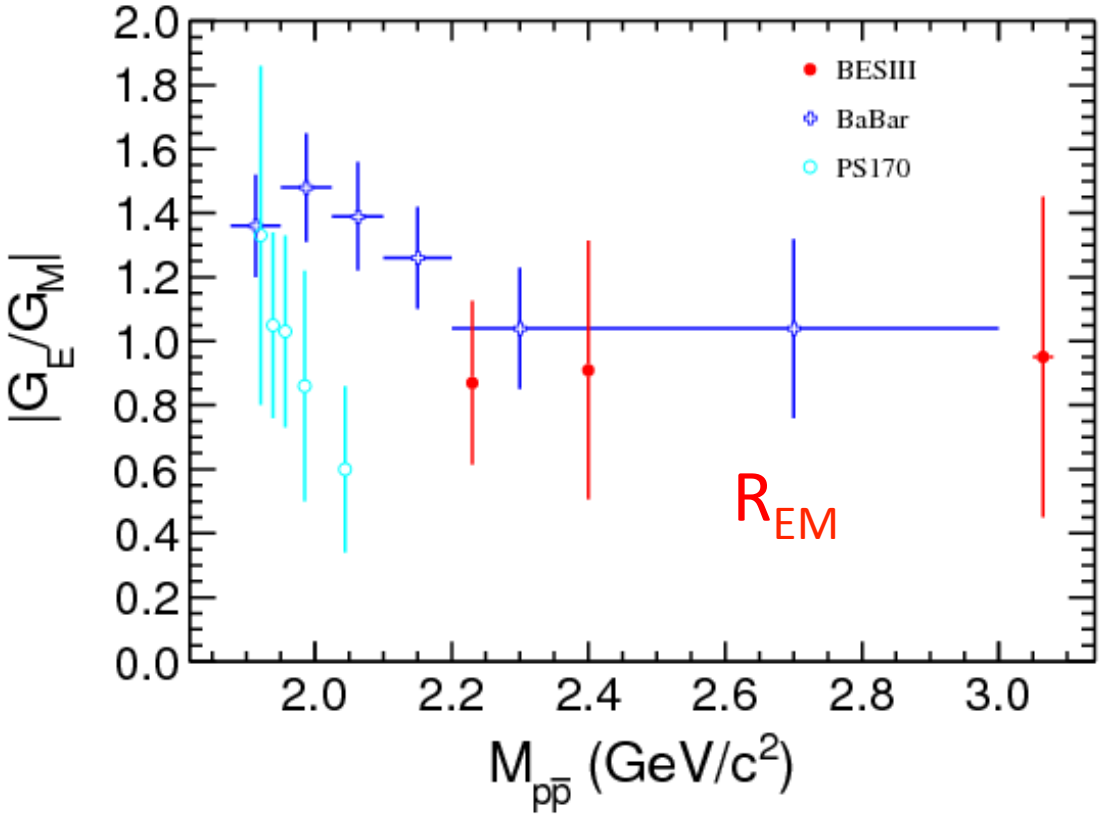


- Dots with error bar: data
- Black line: overall fit
- Red line: magnetic FF contribution
- Blue line: electric FF contribution

E_{cm}(GeV)	χ^2/ndf
2.2324	1.04
2.4	0.74
3.05, 3.06, 3.08	0.61

R_{EM}s are extracted from the fit

Proton FFs at BESIII in $e^+e^- \rightarrow p\bar{p}$ bar



- **Inconsistent** between **Babar** and **PS170**
- **BESIII consistent with Babar** in the same q^2 region
- Close to 1

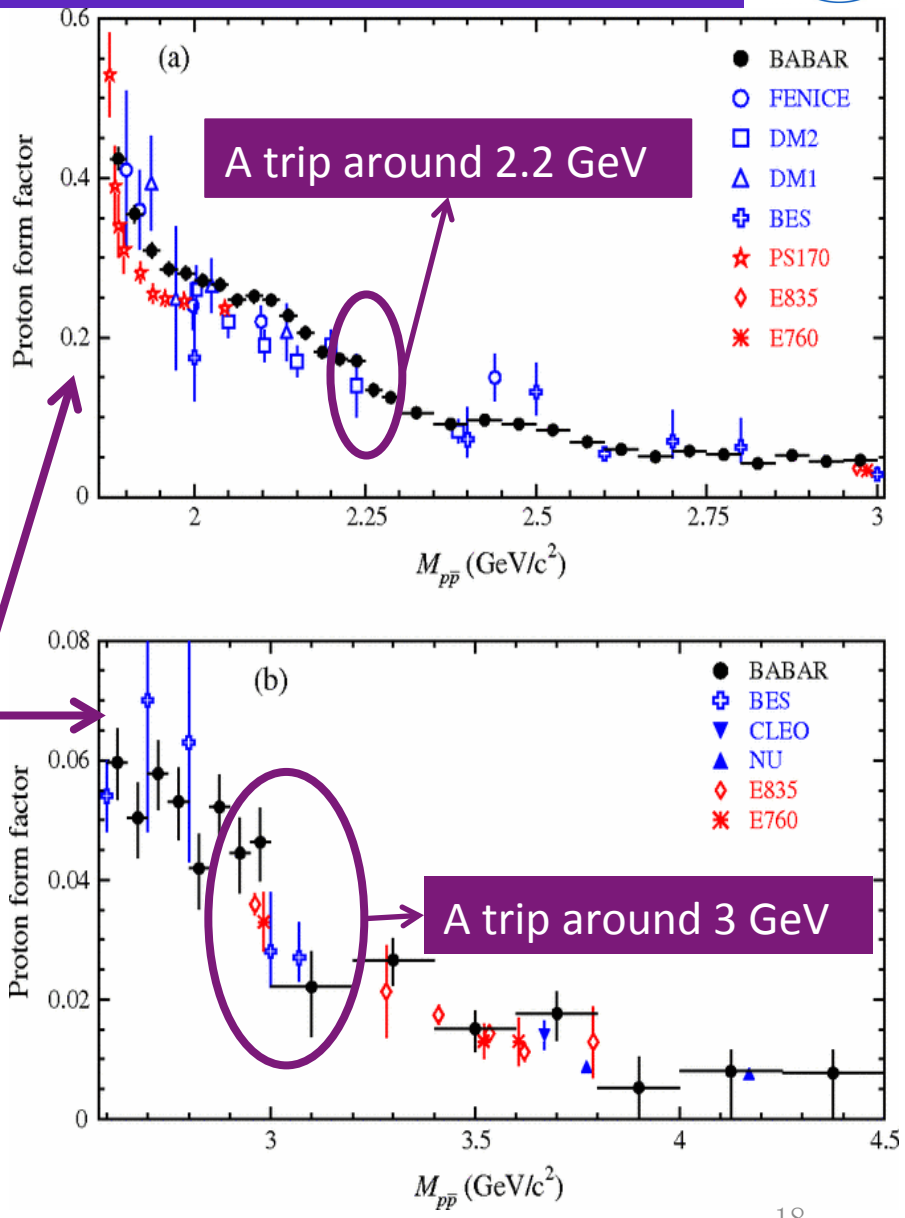
Prospections of proton FFs in $e^+e^- \rightarrow p\bar{p}$ at BESIII

21 energy points between 2-3.08 GeV in 2015, with large statistics.

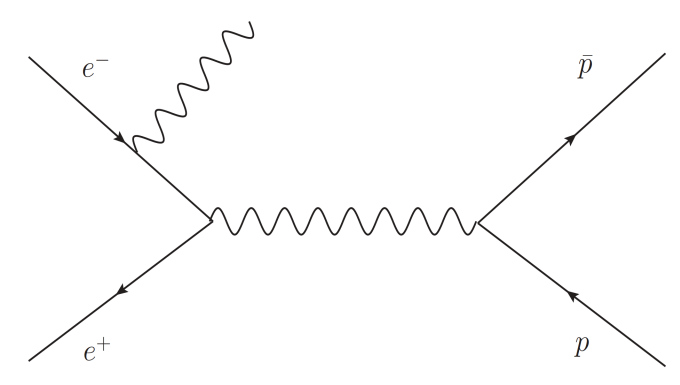
- More precise measurement
- Aim to measure R_{EM} of 10-15% with much narrower q^2-bins

E_{cm}(GeV)	Lumi. (pb-1)	Purpose
2.2	13.0	Nucleon FFs & Y(2175)
2.95	15.7	$m_{p\bar{p}}$ step
2.981	15.4	$m_{p\bar{p}}$ step, η_c
3.0	15.3	$m_{p\bar{p}}$ step
3.02	16.6	

- The 2 trips found by Babar can be studied



Proton FFs in ISR process

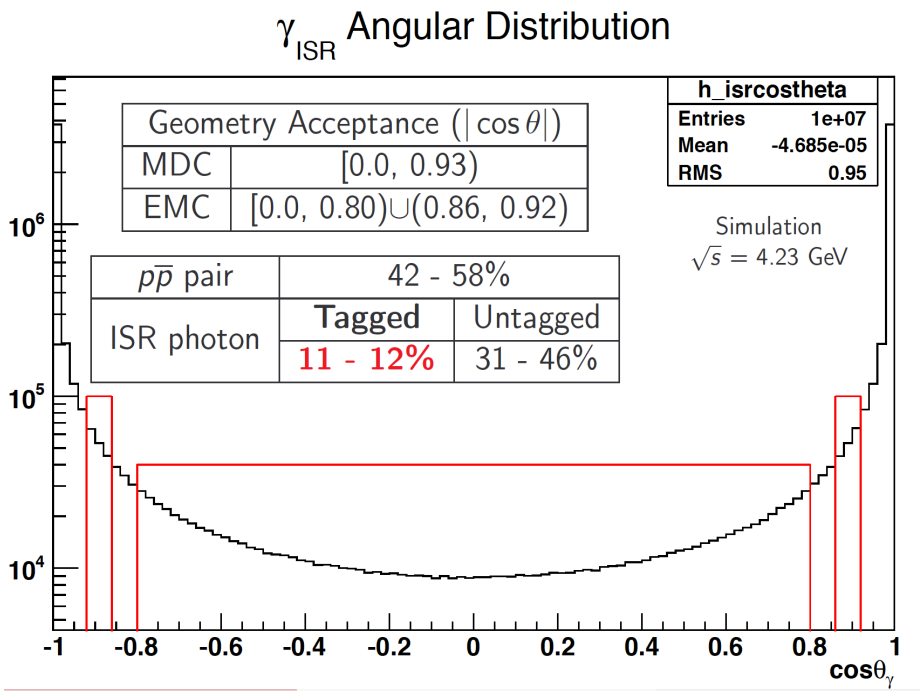


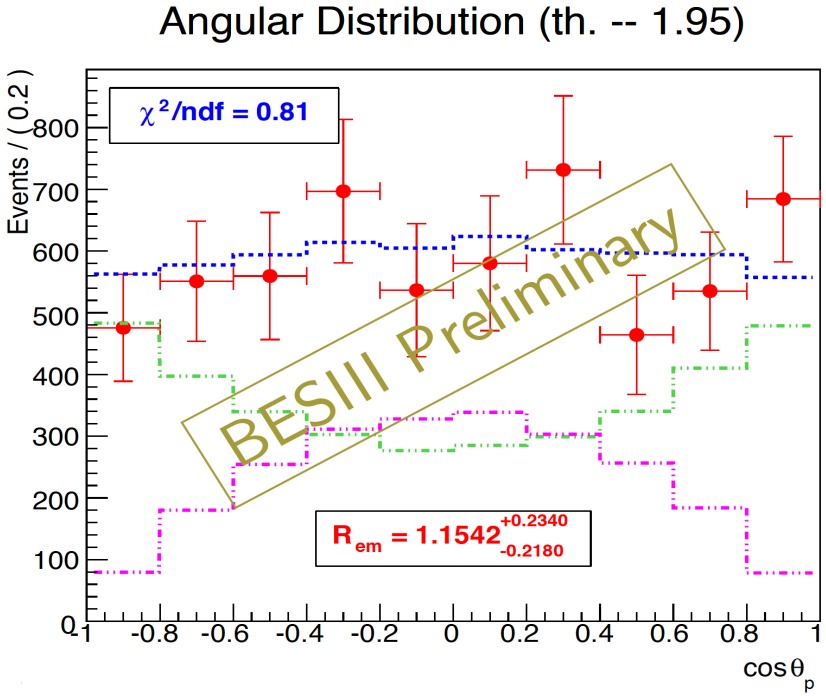
- Tagged method (preliminary results)
- Untagged method (on going)

Datasets using:

E_{cm} (GeV)	3.773	4.009	4.230	4.260	4.360	4.420	4.600
Taking time	2010-2011	2011	2013	2013	2013	2014	2014
Lumi. (pb^{-1})	2917.00	481.96	1047.34	825.67	539.84	1028.89	566.93

Proton FFs at BESIII with ISR (Tagged)





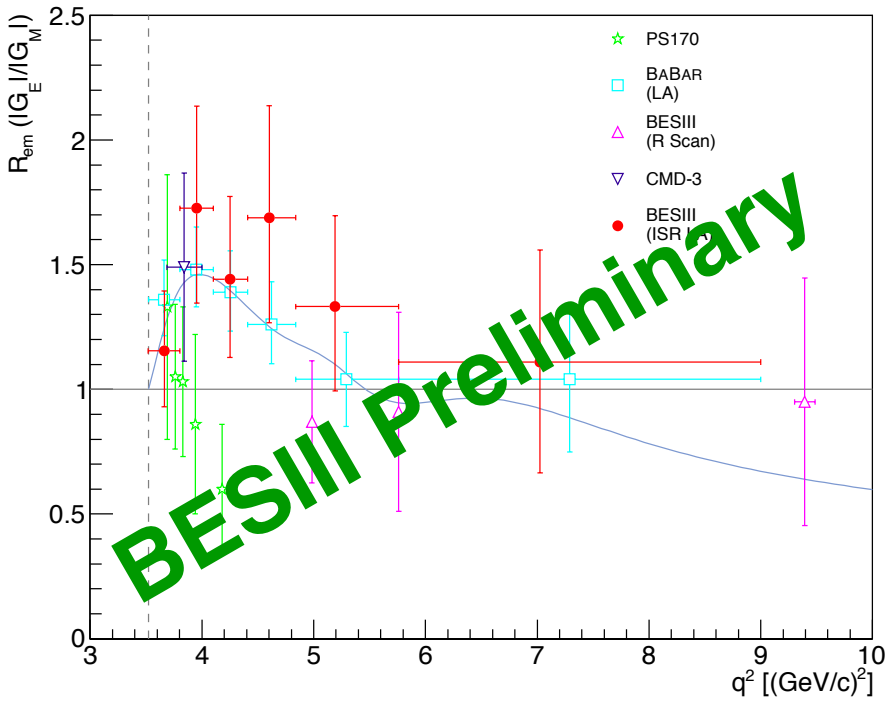
Tagged method: γ is detected

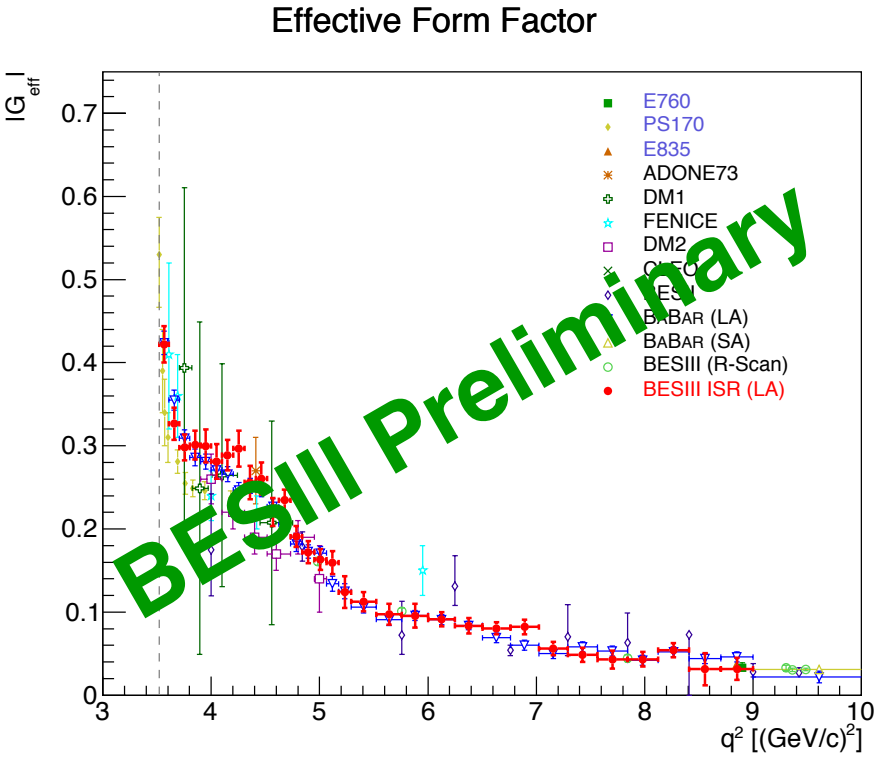
- $E_\gamma > 25$ MeV & $|\cos\theta_\gamma| < 0.8$, in the EMC barrel
- $E_\gamma > 50$ MeV & $0.86 < |\cos\theta_\gamma| < 0.92$, in the EMC endcap

Angular distribution at ~1.95

- Fit is good
- Green dashed line: Magnetic FFs contribution
- Violet dashed line: Electric FFs contribution

Proton FFs at BESIII with ISR (Tagged)





- **Consistent** with Babar and BESIII R scan results

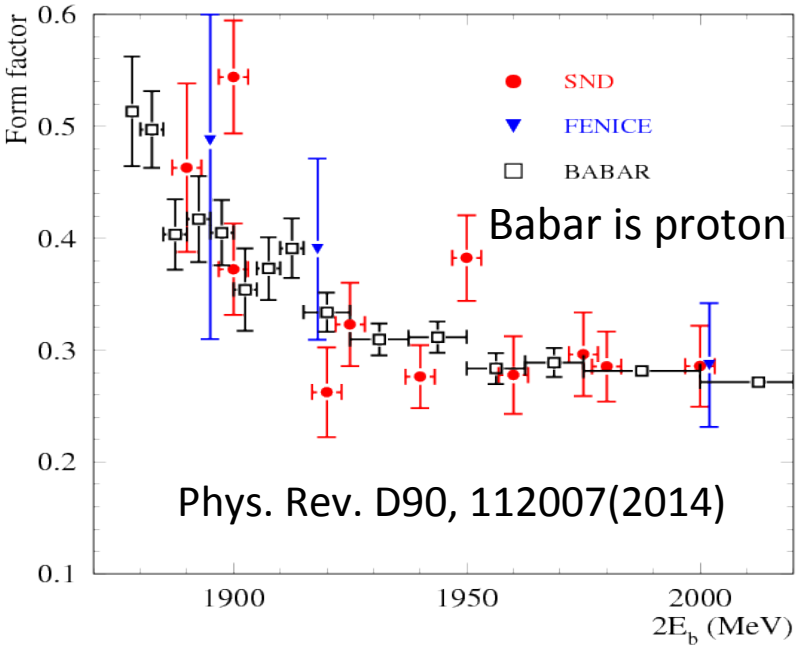
E_{cm}(GeV)	Stat.	Syst.
$\delta R_{EM}/R_{EM}$	16% - 34%	5% - 22%

- Measured in **31** mass intervals
- **Consistent** with previous results

E_{cm}(GeV)	Stat.	Syst.
$\delta G_{Eff}/G_{Eff}$	5% - 32%	2% - 30%

Neutron FFs at BESIII

- The first results obtained by FENICE 20 years ago
- Confirmed by SND recently in 2014
- Compared to the proton FFs from Babar
  - Similar distributions of proton and neutron



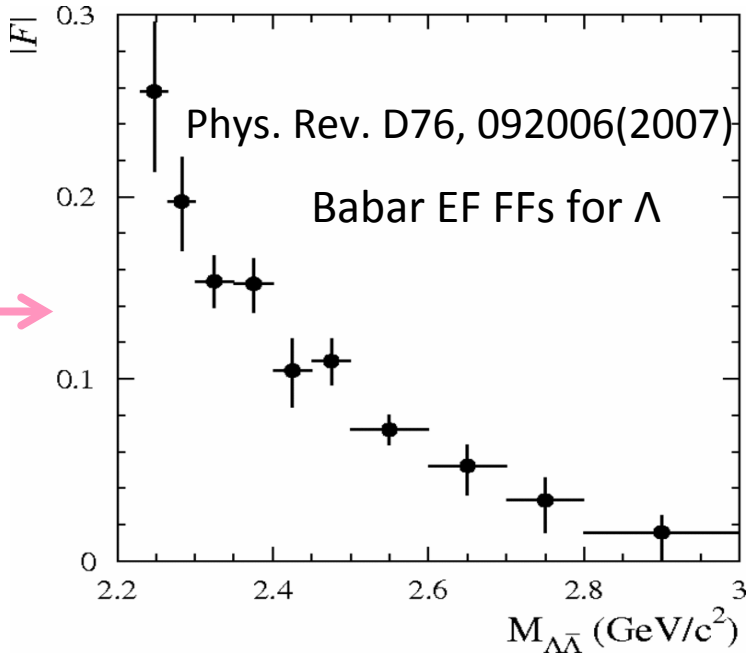
Prospects at BESIII: with data scanned in 2015

- First measurement at BESIII
- Between 2 and 3.08 GeV
- **High statistics**
- **Narrow q^2-bins** (~ 100 MeV)

Hyperon FFs at BESIII

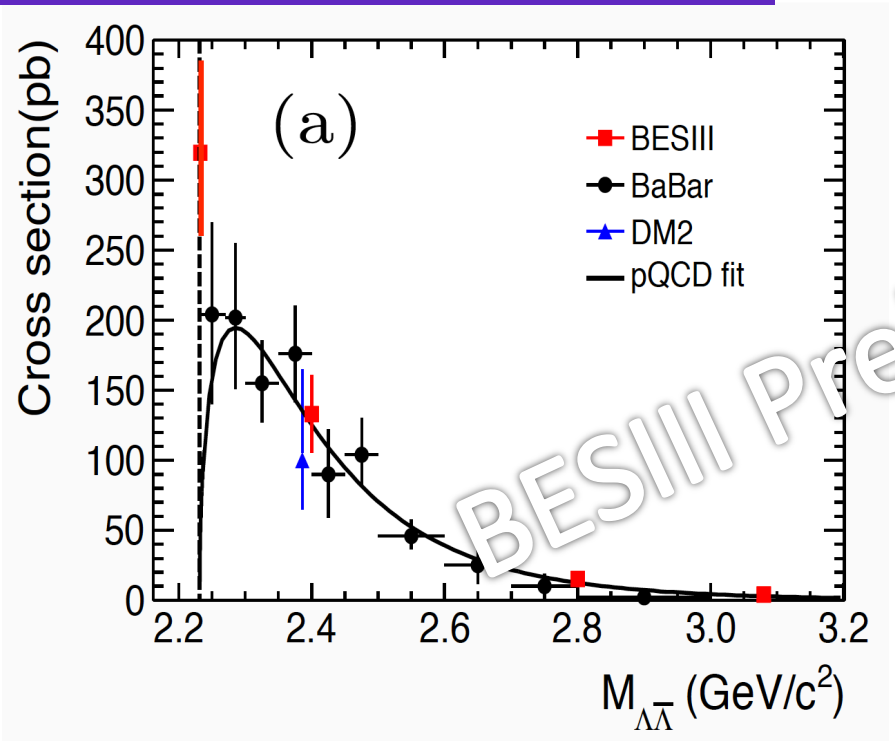
- Λ and Σ^0 FFs were obtained by Babar in processes:

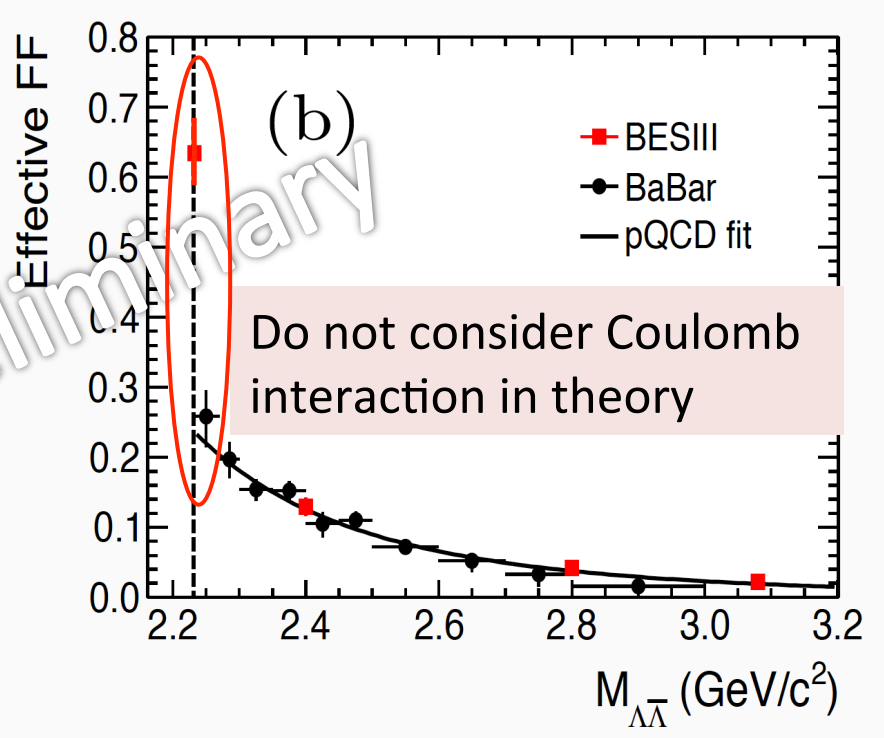
$$e^+e^- \to \gamma\Lambda\bar{\Lambda}, \gamma\Lambda\bar{\Sigma}^0, \gamma\Sigma^0\bar{\Sigma}^0$$



- **Preliminary results** on Λ FFs at BESIII
  - At **4** energy points: 2.2324, 2.4, 2.8, 3.08 GeV with 2015 scan
  - 2.2324 is 1 MeV above Λ threshold

Λ FFs at BESIII





BESIII Preliminary

Do not consider Coulomb interaction in theory

- Results **consistent** with previous measurements
- With **improved** precision
- Cross section and EF FFs are measured **at threshold**
  - **Helpful** in understanding the mechanism of baryon production

Summary

- BESIII already had important results on baryon FFs measurements
- 2012 data scan — proton FFs:
  - Born cross section and EF FFs, with uncertainties improved by ~ 30% compared to Babar
  - R_{EM} and G_M
  - Preliminary results of ISR process with tagged method
- 2015 data scan — more baryon FFs:
  - Preliminary results on Λ FFs
  - Prospect to improve proton FFs measurements
  - Prospect to have first results of neutron FFs at BESIII
  - Prospect to have $\Sigma^{\pm}$ and Σ^0 FFs at one energy

Thank you for your attention!

Back-up

Measurements of baryon FFs

Electromagnetic FFs:

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

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

How to measure? ⟵ Angular analysis

SL:

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \left[G_E^2 + \frac{\tau}{\varepsilon} G_M^2\right] \frac{1}{1+\tau}$$

$$\varepsilon = 1 \Big/ \left[1 + 2(1+\tau)\tan^2\frac{\theta}{2}\right]$$

$$\tau = q^2 / \left(4M_B^2\right)$$

TL:

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2 \beta \zeta}{4q^2} \left[\frac{1}{\tau}\sin^2\theta |G_E|^2 + \left(1+\cos^2\theta\right)|G_M|^2\right]$$

$$\beta = \sqrt{1 - 1/\tau}$$

ζ : Coulomb correction