Hadron form factors at BESIII

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on behalf of BESIII Collaboration

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Outline

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

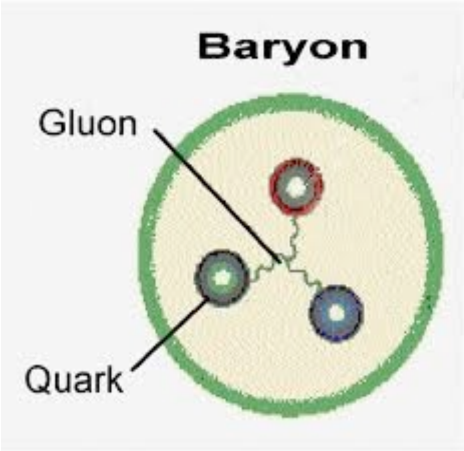
Form factor

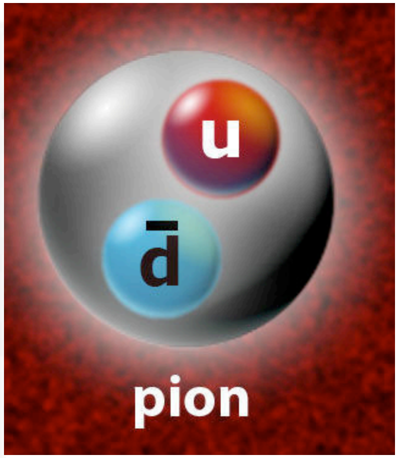
1

Hadrons have structure

FFs describe hadrons' internal structure

Understanding hadrons' structure **helps understand QCD**





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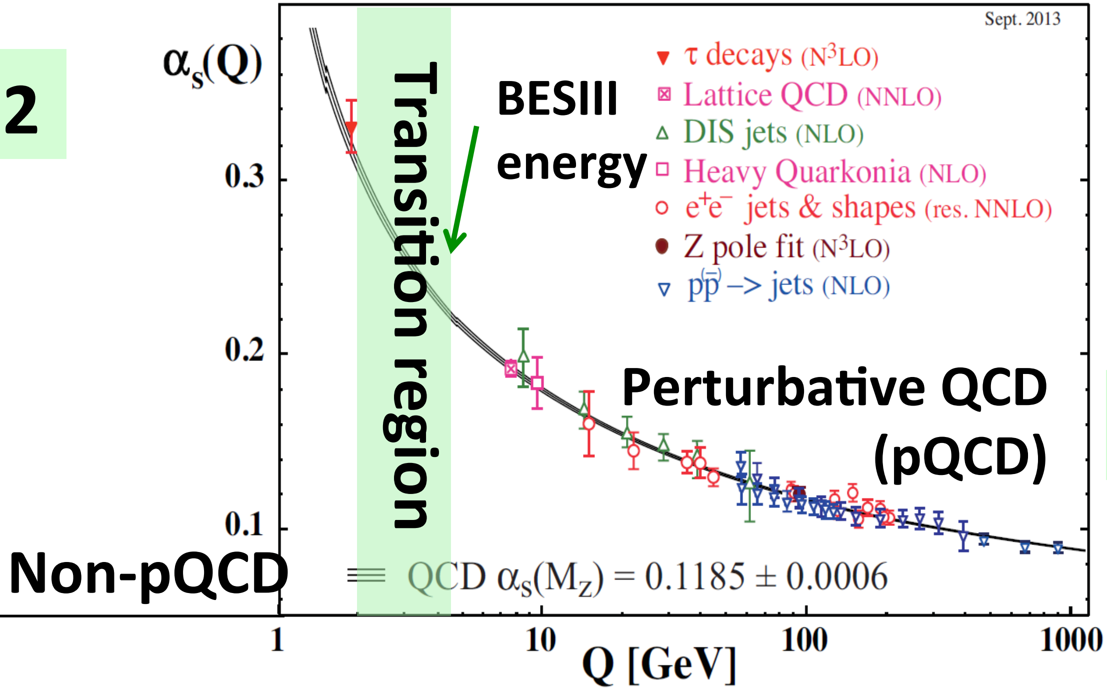
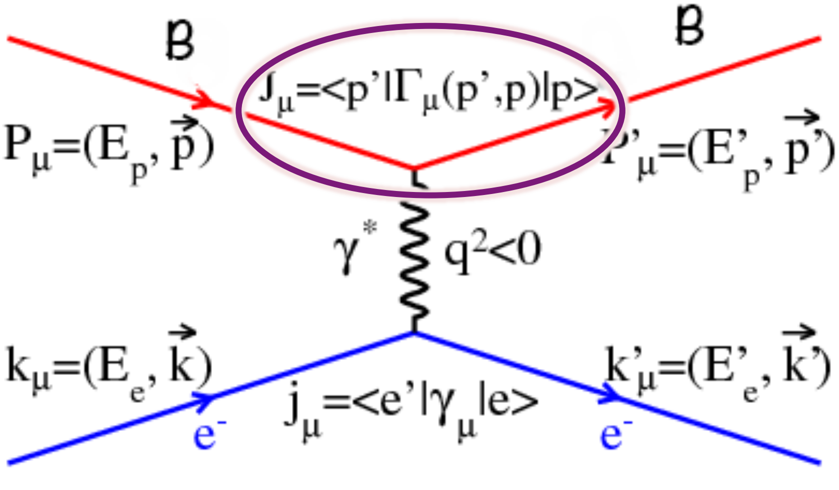
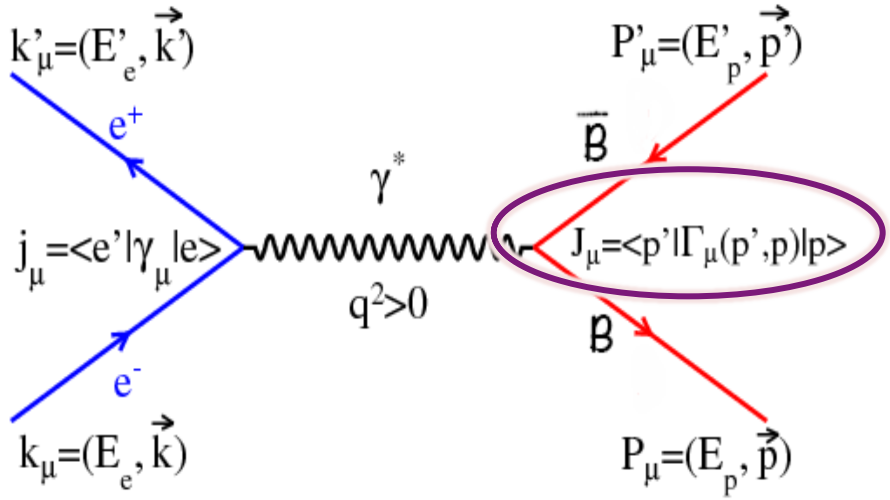


FFs help understand strong interaction

Inputs to QCD models

Dirac FF and Pauli FF





Elastic scattering:

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

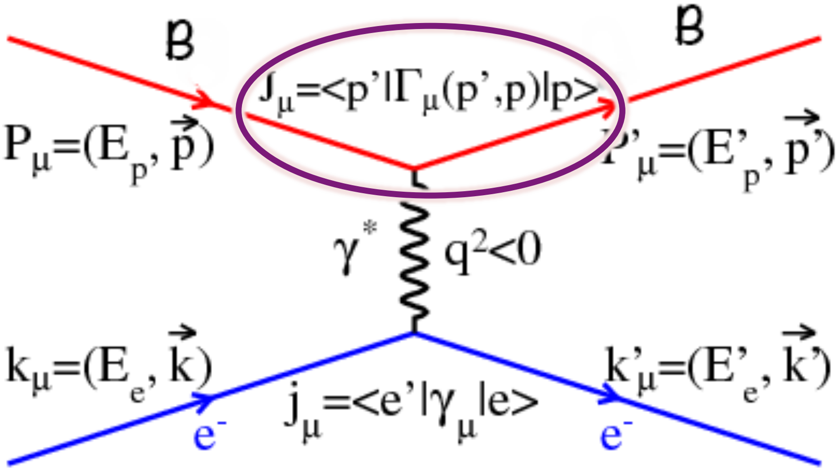
Annihilation:

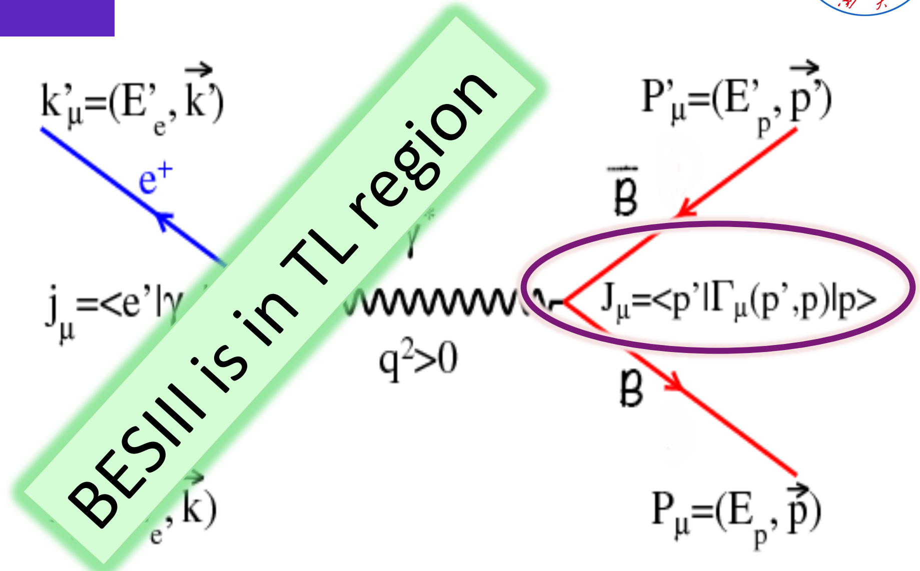
Time-like (TL) region, $q^2 > 0$

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





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

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

EM FFs and TL angular distribution

EM FFs:

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

Electric

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

Magnetic

How to measure them? → Angular analysis

TL:

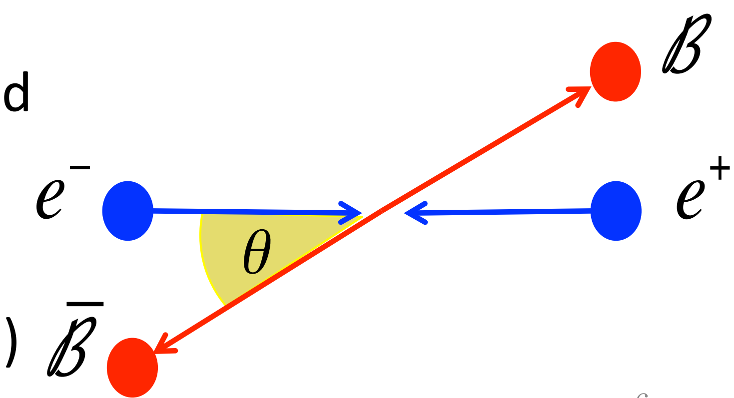
$$\frac{d\sigma_{born}}{d\Omega} = \frac{\alpha^2 \beta C}{4s}\left[\frac{1}{\tau}\sin^2\theta |G_E|^2 + (1+\cos^2\theta)|G_M|^2\right]$$

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

C : Coulomb correction

function of s and θ:

- s=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:

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

Ratio of EM FFs:

$$R_{EM}=\left|G_E(s)/G_M(s)\right|$$

Born cross section:

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

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

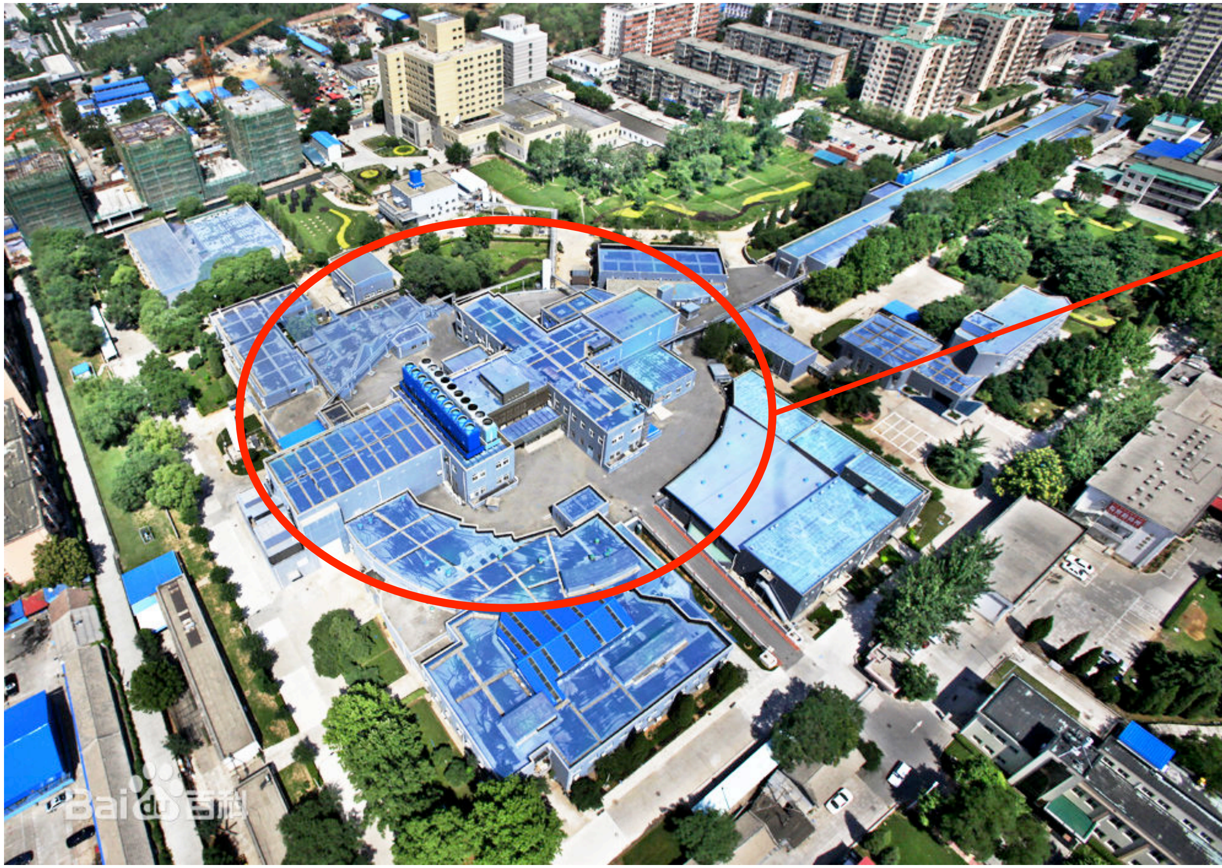
EF FFs:

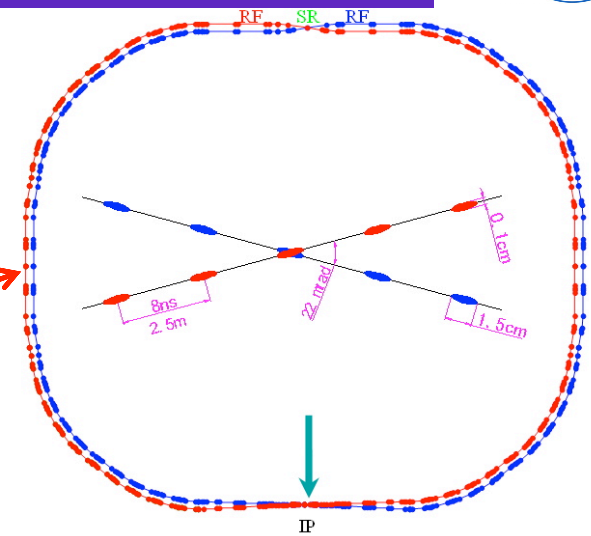
$$|G(s)|=\sqrt{\sigma_{born}\Big/\left[\frac{4\pi\alpha^2\beta C}{3s}\left(1+\frac{1}{2\tau}\right)\right]}$$

Above baryon threshold: C=1

All formula valid for spin 1/2

BEPCII (Beijing Electron Positron Collider II)

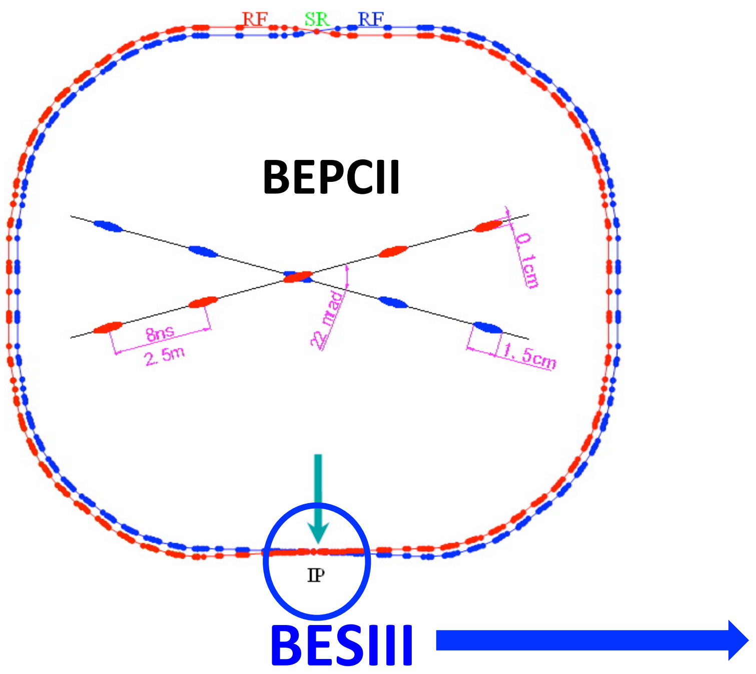


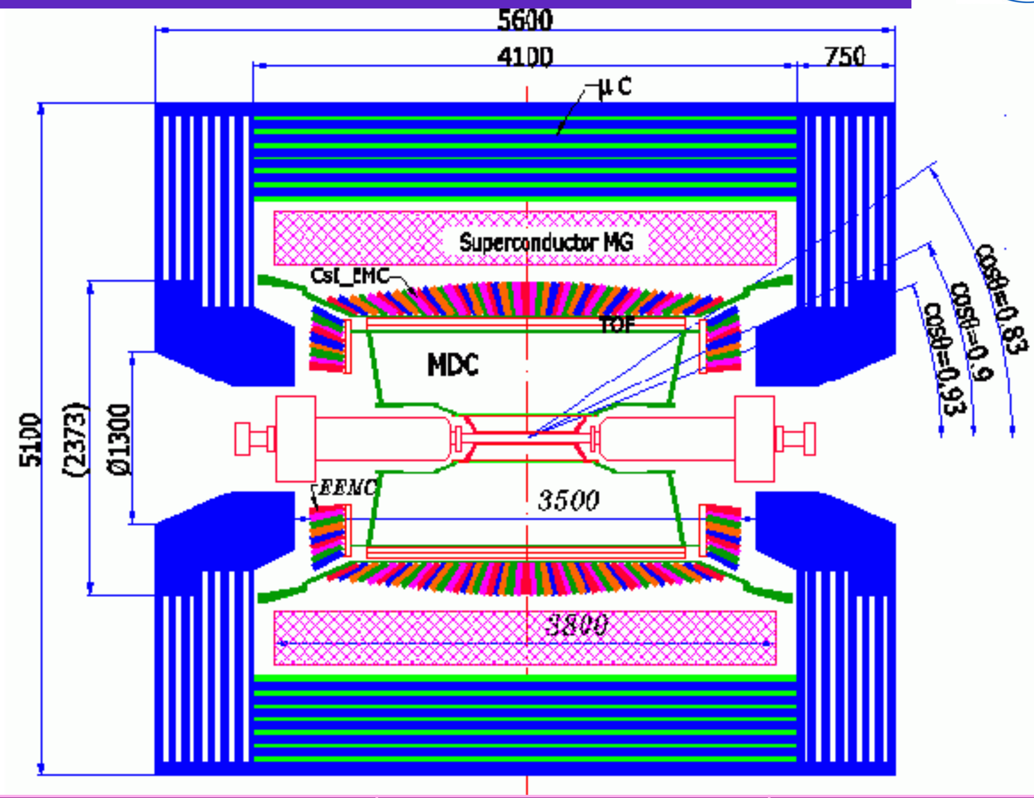


- Runs started in 2009
- CM energy: **2.0 – 4.6 GeV**
- "τ-charm factory"

- 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 (BEijing Spectrometer III) at BEPCII



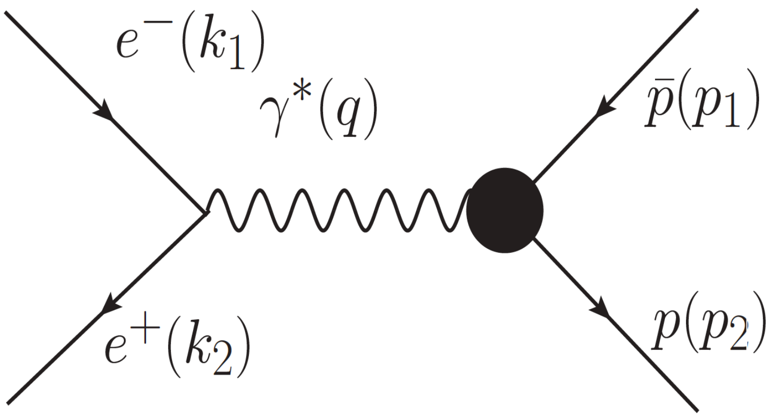


	MDC	TOF	EMC	MUC
Sub-detectors	Main Drift Chamber	Time of Flight	Electromagnetic Calorimeter	Muon Counter
Resolution	115μm(wire), < 5% (dE/dx)	68ps (Barrel), 70ps (Endcap)	2.3% (energy)	

Outline

- Definition of baryon form factors (FFs)
- BEPCII & BESIII detector
- Status of baryon FFs measurements
  - Proton FFs
    - $e^+e^- \to p\bar{p}$ process
    - ISR (Initial State Radiation) process
  - Neutron FFs
  - Hyperon FFs
- Status of meson FFs measurements
- Summary

Proton FFs in $e^+e^- \to p\bar{p}$



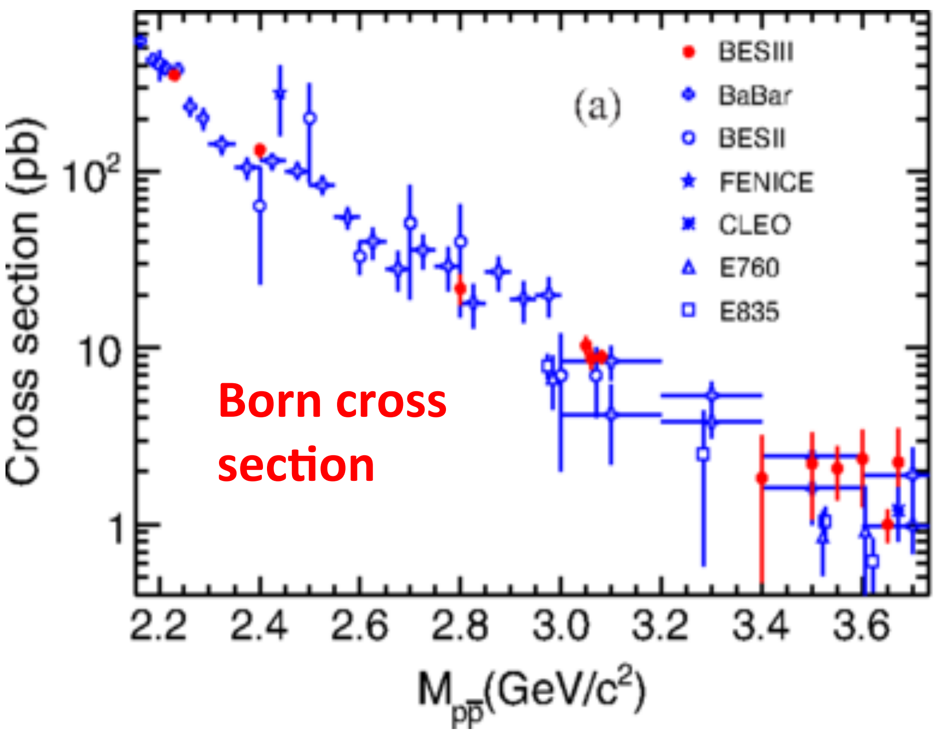
Energy scan method

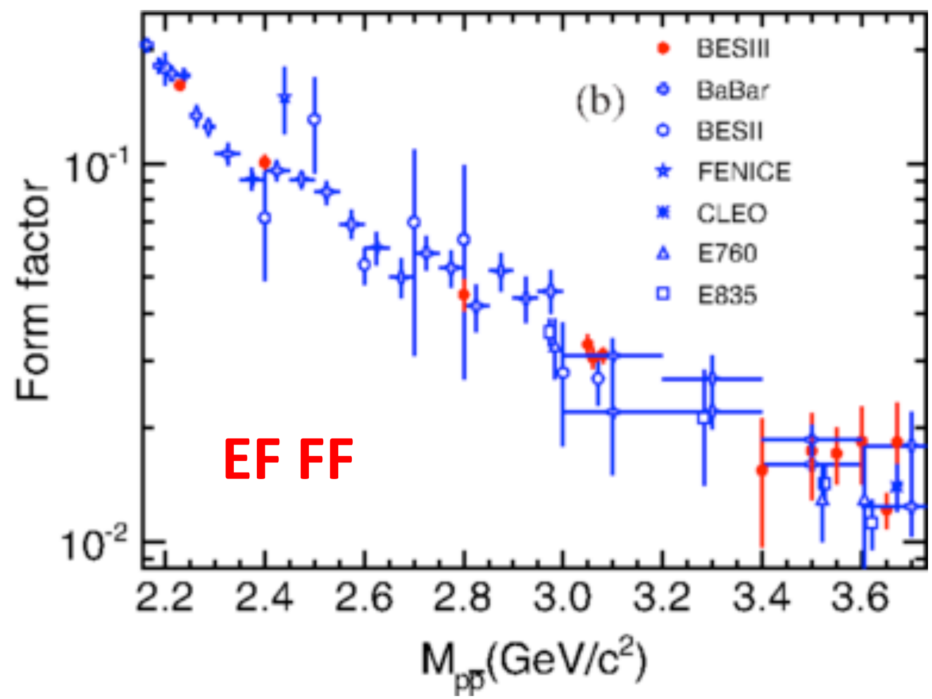
Proton FFs at BESIII in $e^+e^- \rightarrow p\bar{p}$

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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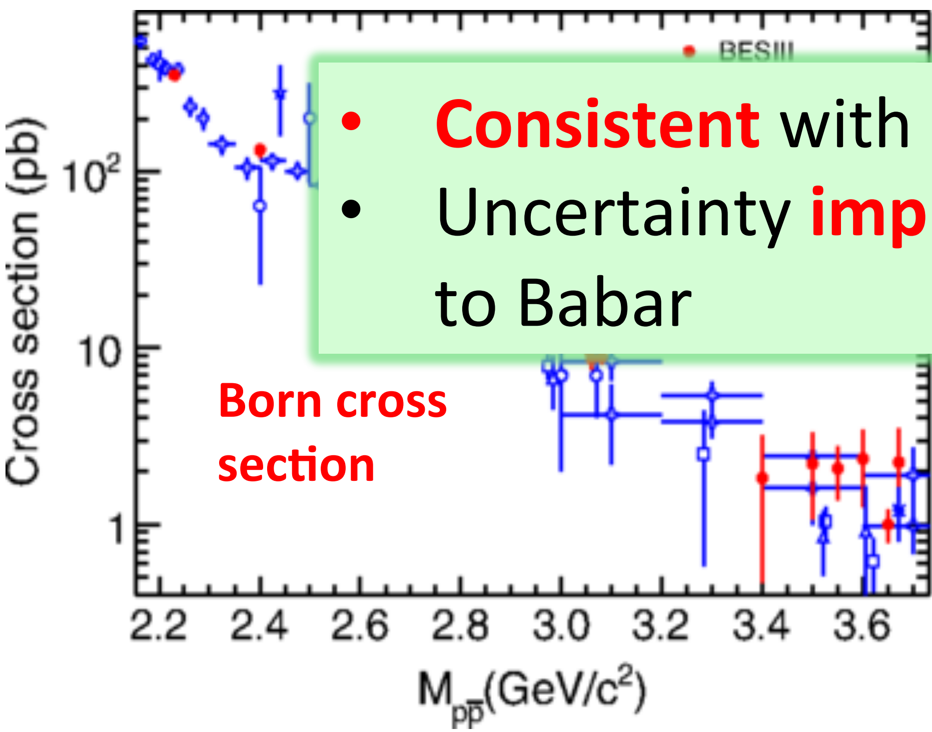
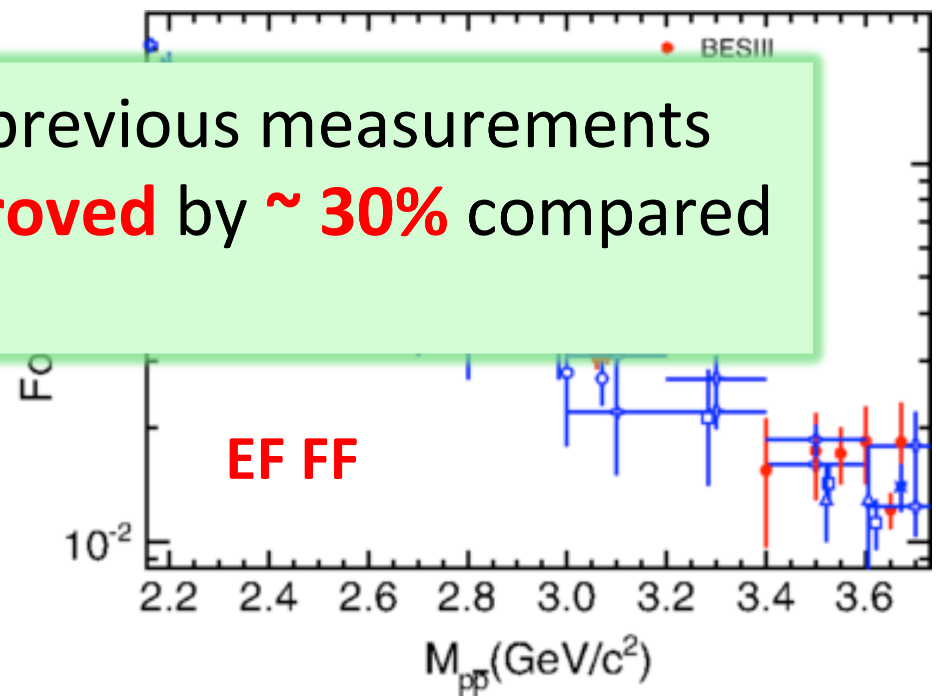


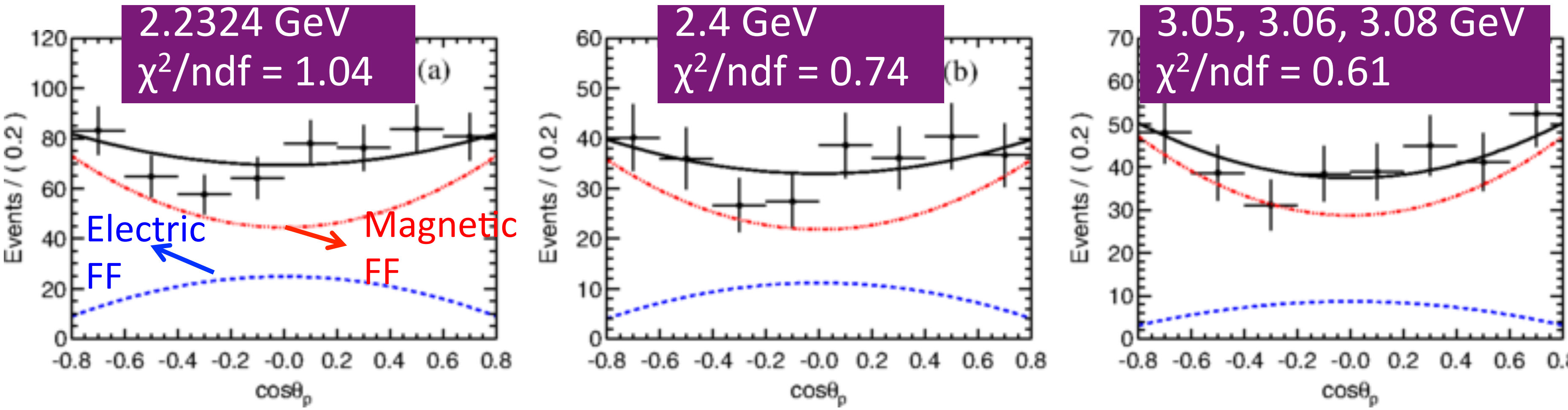


- **Consistent** with previous measurements
- Uncertainty **improved** by **~ 30%** compared to Babar

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

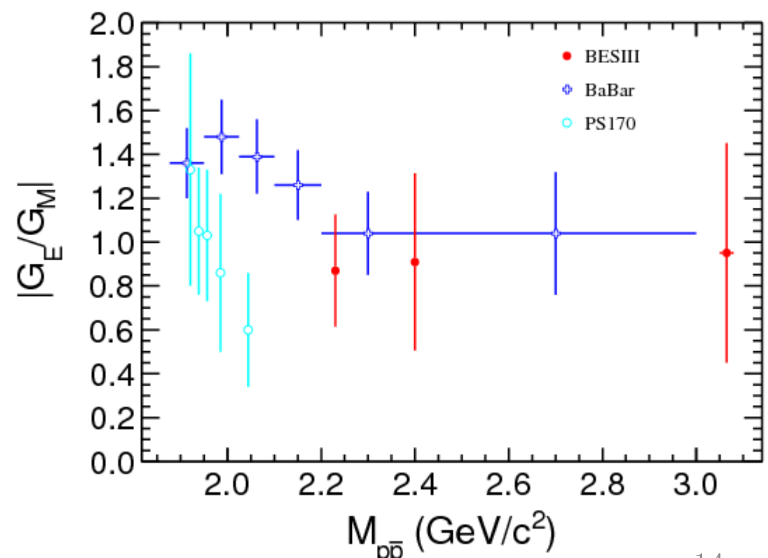
Phys. Rev. D 91, 112004 (2015)

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



R_{EM}s are extracted from the fit

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



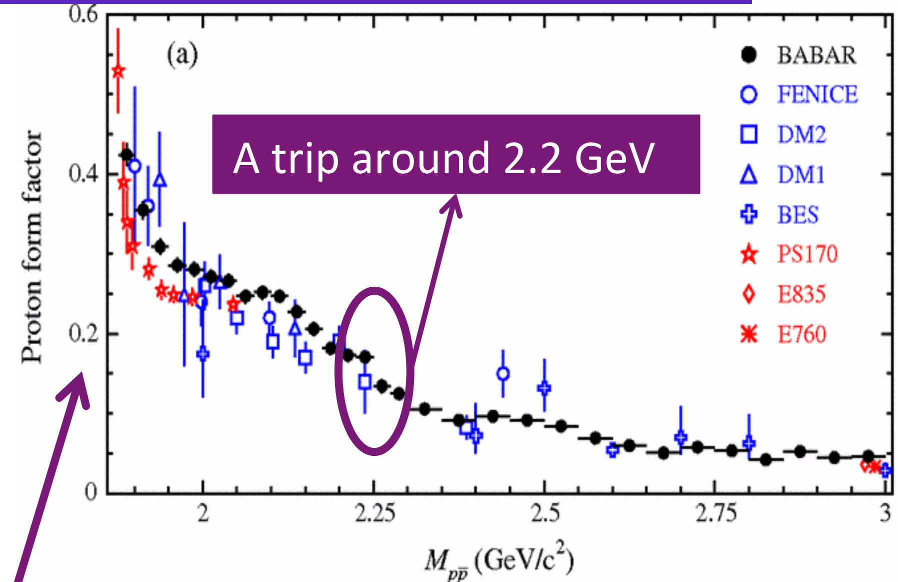
Prospections of proton FFs in $e^+e^- \rightarrow p\bar{p}$ at BESIII

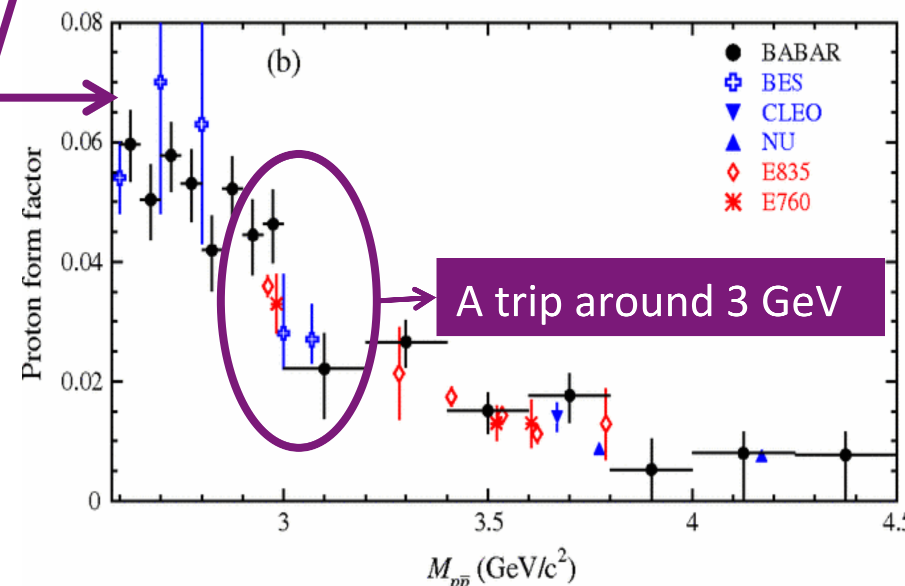
21 energy points between 2-3.08 GeV in 2015, with large statistics.

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

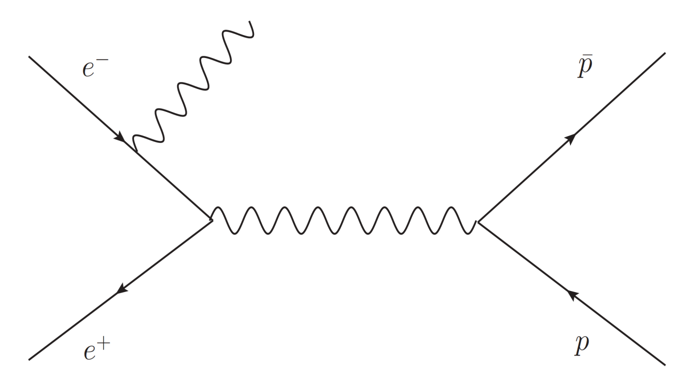
E_{cm}(GeV)	Lumi. (pb-1)	Purpose
2.2	13.0	Nucleon FFs & Y(2175)
2.95	15.7	$m_{p\bar{p}}$ step
2.981	15.4	$m_{p\bar{p}}$ step, η_c
3.0	15.3	$m_{p\bar{p}}$ step
3.02	16.6	

- The 2 trips found by Babar can be studied





Proton FFs in ISR process



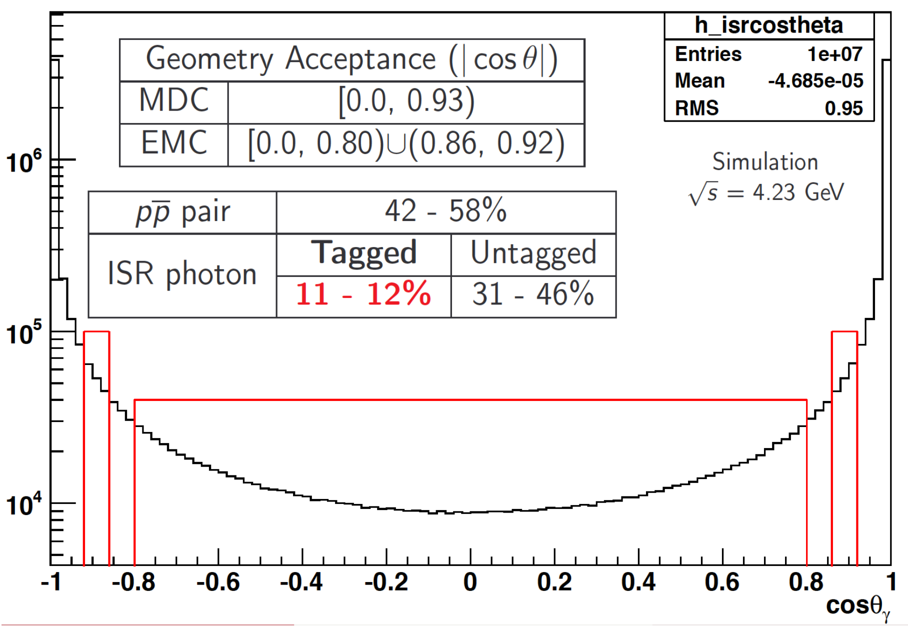
- Tagged method (preliminary results)
- Untagged method (on going)

Datasets using:

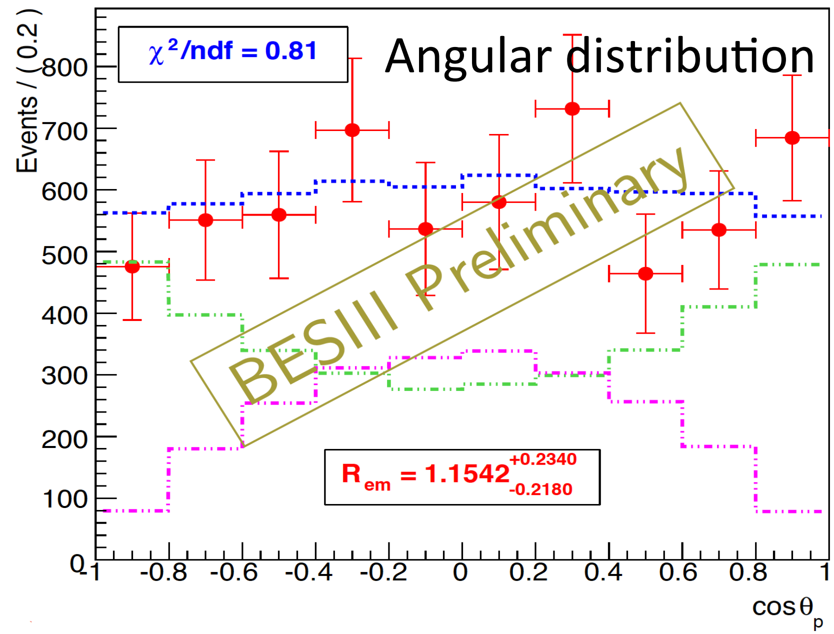
E_{cm} (GeV)	3.773	4.009	4.230	4.260	4.360	4.420	4.600
Taking time	2010-2011	2011	2013	2013	2013	2014	2014
Lumi. (pb^{-1})	2917.00	481.96	1047.34	825.67	539.84	1028.89	566.93

Proton FFs at BESIII with ISR (Tagged)

γ_{ISR} Angular Distribution



proton threshold – 1.95 GeV



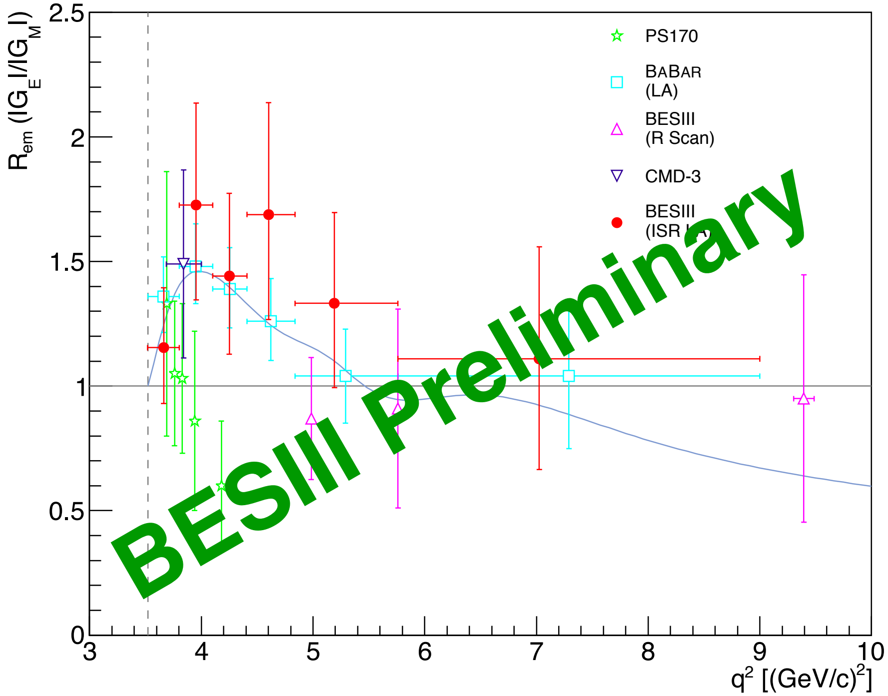
Tagged method: γ is detected

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

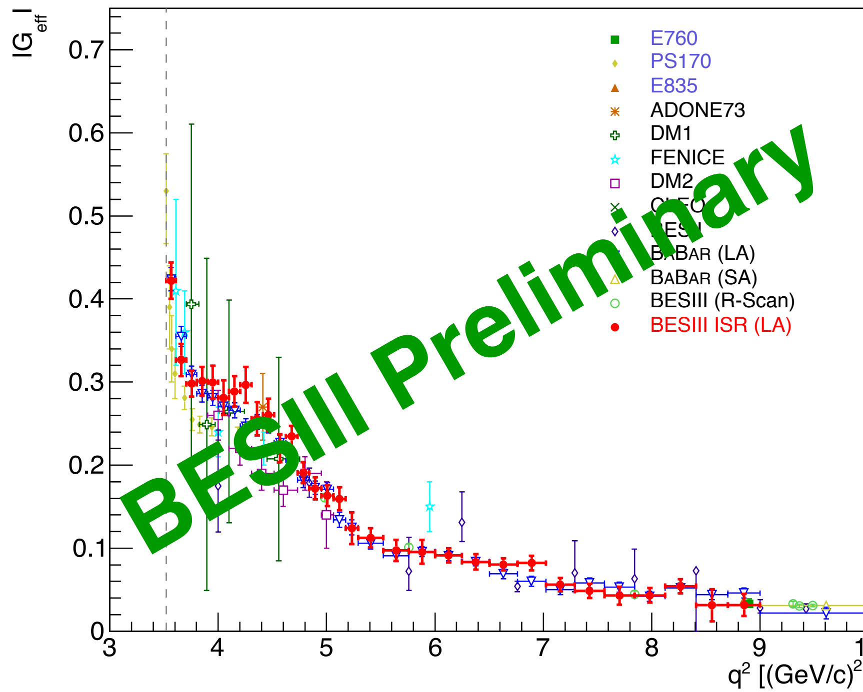
Angular distribution at ~1.95

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

Proton FFs at BESIII with ISR (Tagged)



Effective Form Factor



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

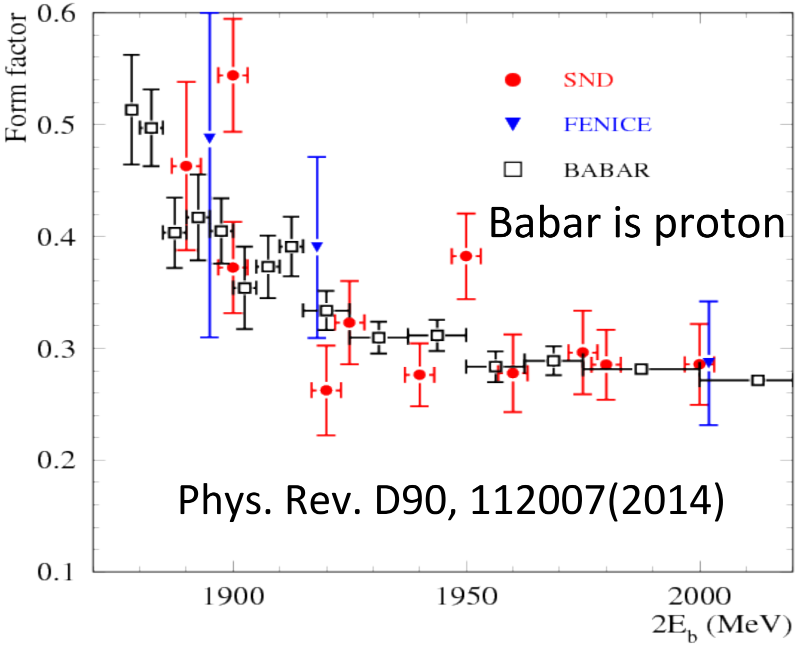
- Measured in **31** mass intervals
- **Consistent** with previous results

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

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

Baryon born cross section:

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

$\beta = \sqrt{1-4m^2/s}$

Neutral: $C = 1$

Charged: $C = \frac{\pi\alpha}{\beta}\frac{1}{1-\exp(-\pi\alpha/\beta)}$

Expecting at threshold:

- For neutral baryon, cross section should almost vanish
  - And increases with √s
- For charged baryon, cross section is non-zero

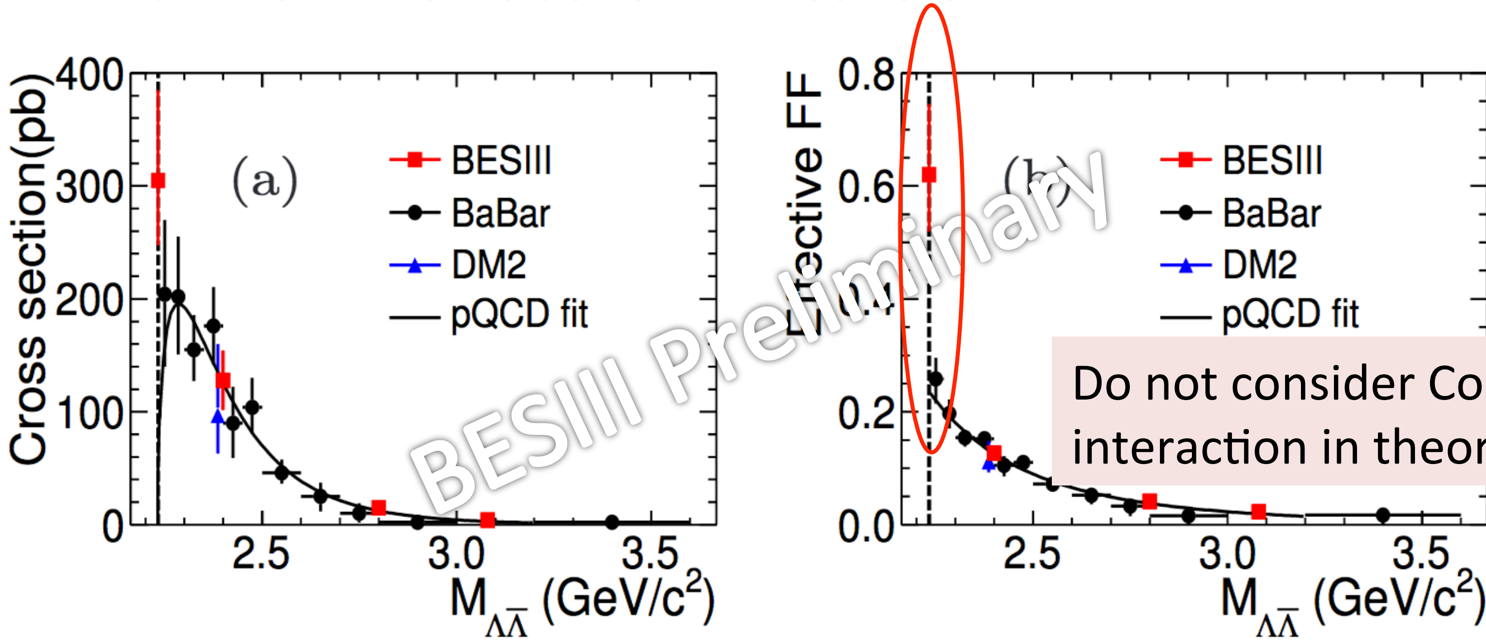
Measurement near threshold:

- Help to understand the Coulomb factor when baryon pair produced, which is not as expected presently in many cases
  - And this factor may connect to the dark matter search
- More deeply to understand the baryon structure

Hyperon FFs at BESIII

• Preliminary results on Λ FFs

- At **4** energy points: 2.2324, 2.4, 2.8, 3.08 GeV with 2015 scan
- 2.2324 is 1 MeV above Λ threshold



Do not consider Coulomb interaction in theory

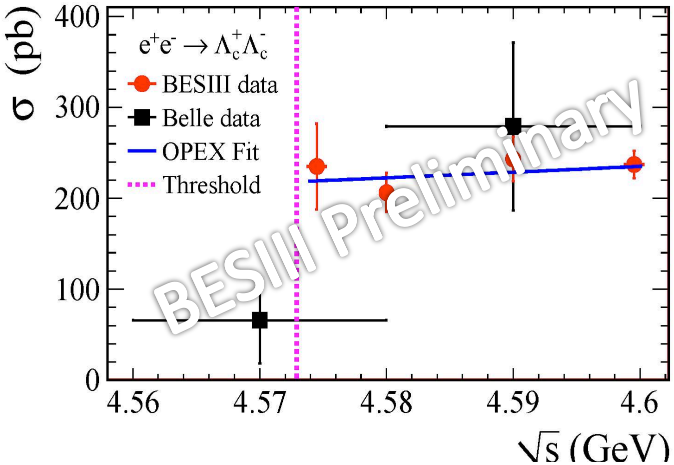
- Results **consistent** with previous measurements
- With **improved** precision
- Cross section and EF FFs are measured **near threshold**
  - **Helpful** in understanding the mechanism of baryon production

Hyperon FFs at BESIII

• Preliminary results on Λ_C FFs

– At **2** energy points: 4.5745 and 4.5996 GeV from 2011 to 2014

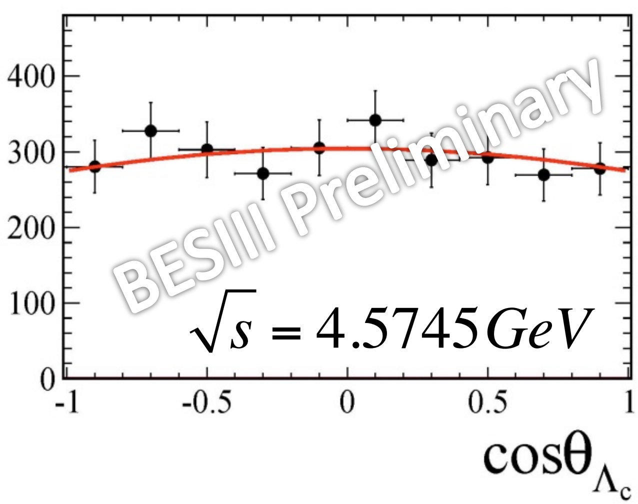
  – 4.5745 GeV is 1.6 MeV above Λ_C threshold



- **Weak** energy dependence near threshold
- **Strong interaction should** be considered into traditional theoretical prediction

FFs:

GeV	$\lvert G_E/G_M \rvert$
4.5745	$1.14 \pm 0.14 \pm 0.07$
4.5995	$1.23 \pm 0.05 \pm 0.03$



- The Λ_C form factor ratio $\lvert G_E/G_M \rvert$ is measure the **first time**
- Provide **important insights** to production mechanism and structure of baryons

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- Definition of baryon form factors (FFs)
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- Status of meson FFs measurements
  - Results on charged kaon and pion FF measurements
- Summary

Meson FFs at BESIII

Meson form factor extraction in $e^+e^- \to (\gamma)M^+M^-$:

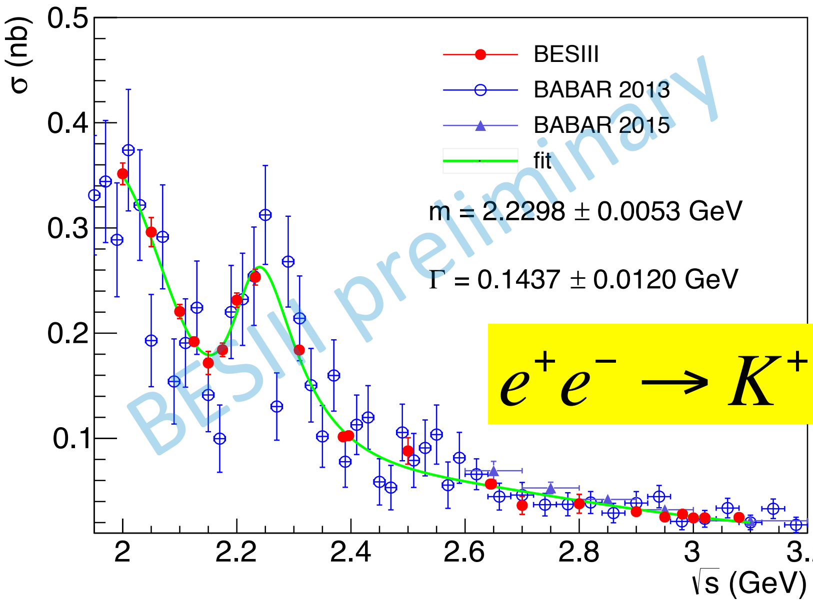
$$|F_M|^2(s) = \frac{3s}{\pi\alpha(0)^2\beta_M^3}\frac{\sigma_{MM}(s)}{C_{FS}} \qquad \sigma_{MM}(s) = \sigma_{MM}^0(s)\left[\frac{\alpha(s)}{\alpha(0)}\right]^2$$

σ_{MM} : dressed cross section; σ_{MM}^0 : bare cross section;

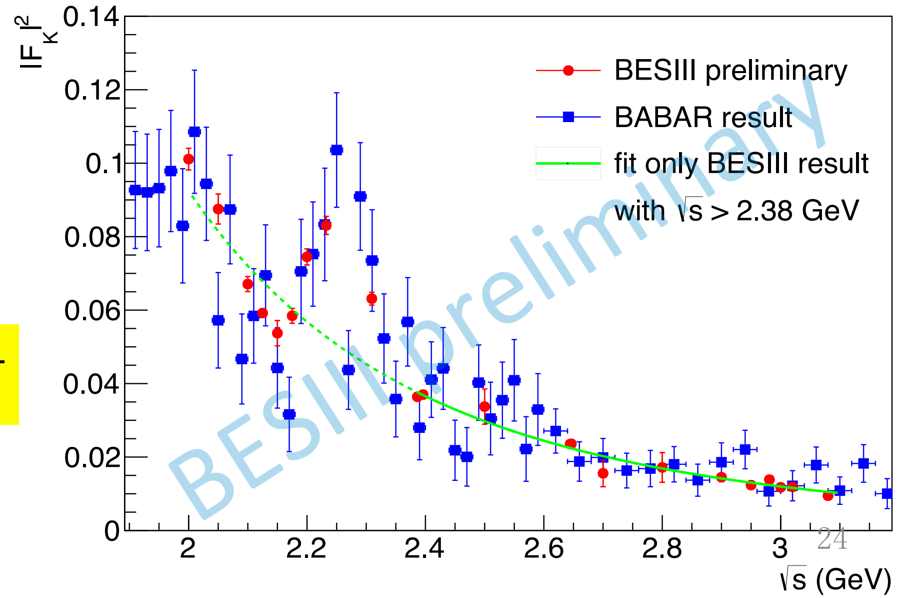
C_{FS} : final-state correction $\beta_M = \sqrt{1-4m_M^2/s}$

- Preliminary results on charged K meson FFs

20 energy points 2.0 – 3.08 GeV, collected in 2015



$$e^+e^- \to K^+K^-$$



Meson FFs at BESIII

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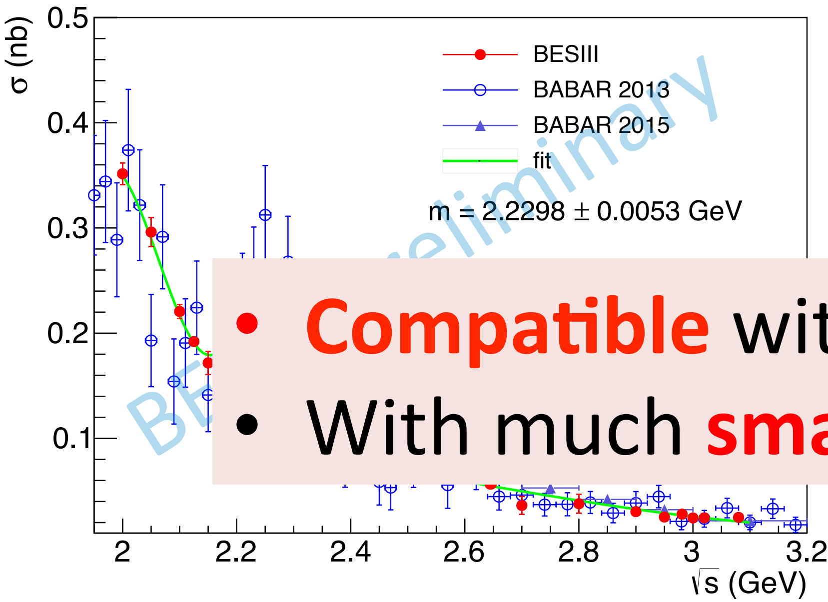

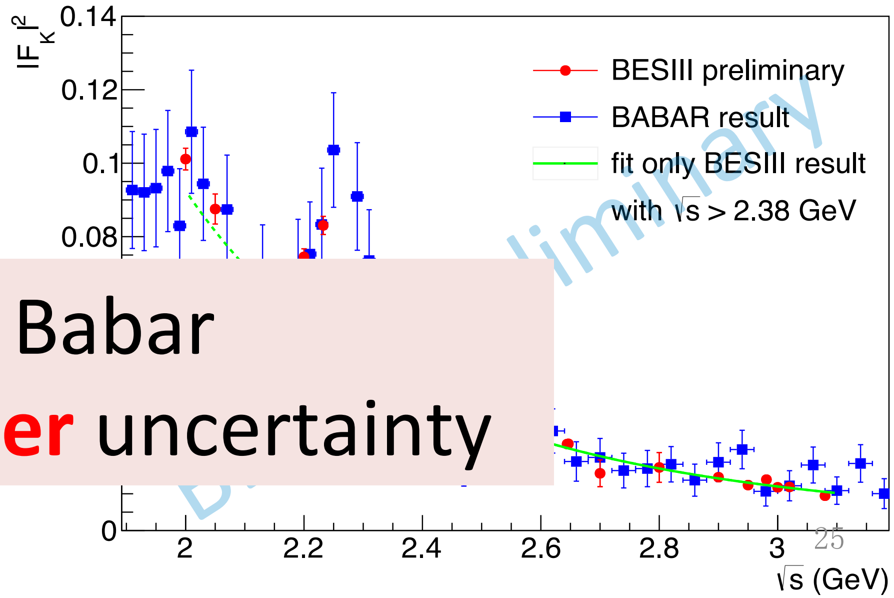

- **Compatible** with Babar
- With much **smaller** uncertainty

Summary

- BESIII already had important results on hadron FFs measurements
- **Baryon FFs:**
  - Proton, Λ, Λ_C results published or preliminary
  - Prospect to have more results with 2015 scan data
- **Meson FFs:**
  - Preliminary results on charged kaon FFs
  - Prospect to have more results on meson FFs, like neutral kaon, with 2015 scan data
  - Results on pion (Please see Marco DESTEFANIS' talk)

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:

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

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

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

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