HIM
Helmholtz-Institut Mainz

BESIII

PRISMA
Cluster of Excellence

BESIII results on time-like baryon form factors

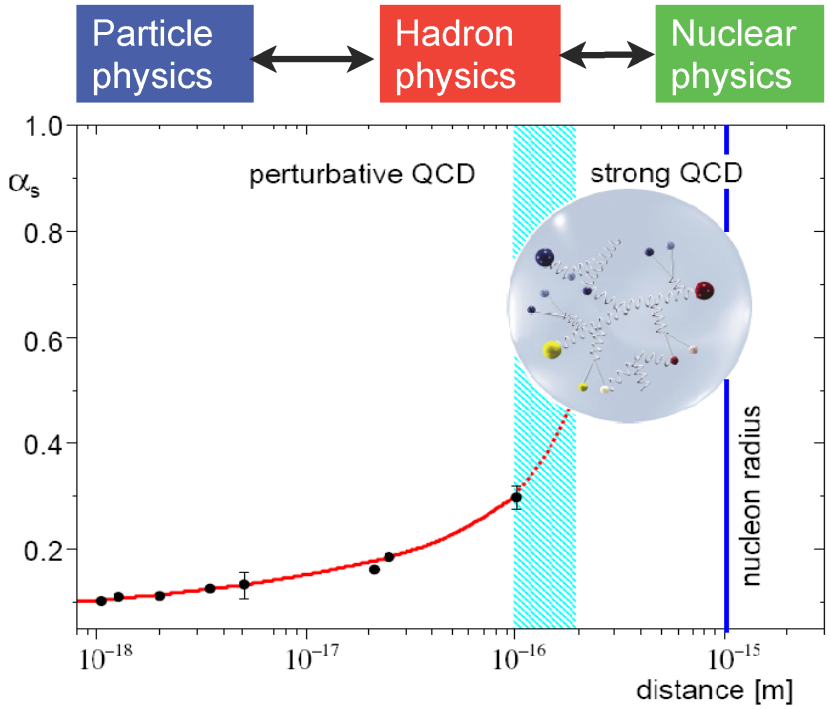
Alaa Dbeyssi (Helmholtz-Institut Mainz)

On behalf of BESIII collaboration

International Workshop on e^+e^- collisions from Phi to Psi 2017
June 28, 2017 Mainz, Germany

The structure of hadrons

- Hadrons: non-perturbative systems



- Their electromagnetic interactions can be described by long distance functions:
  - Electromagnetic form factors,
  - Parton Distribution Amplitudes,
  - Fragmentation Functions,
  - Generalized Parton Distributions,
  - …..

- By a global analysis of scattering and annihilation experiments one can determine these functions and understand the hadron structure

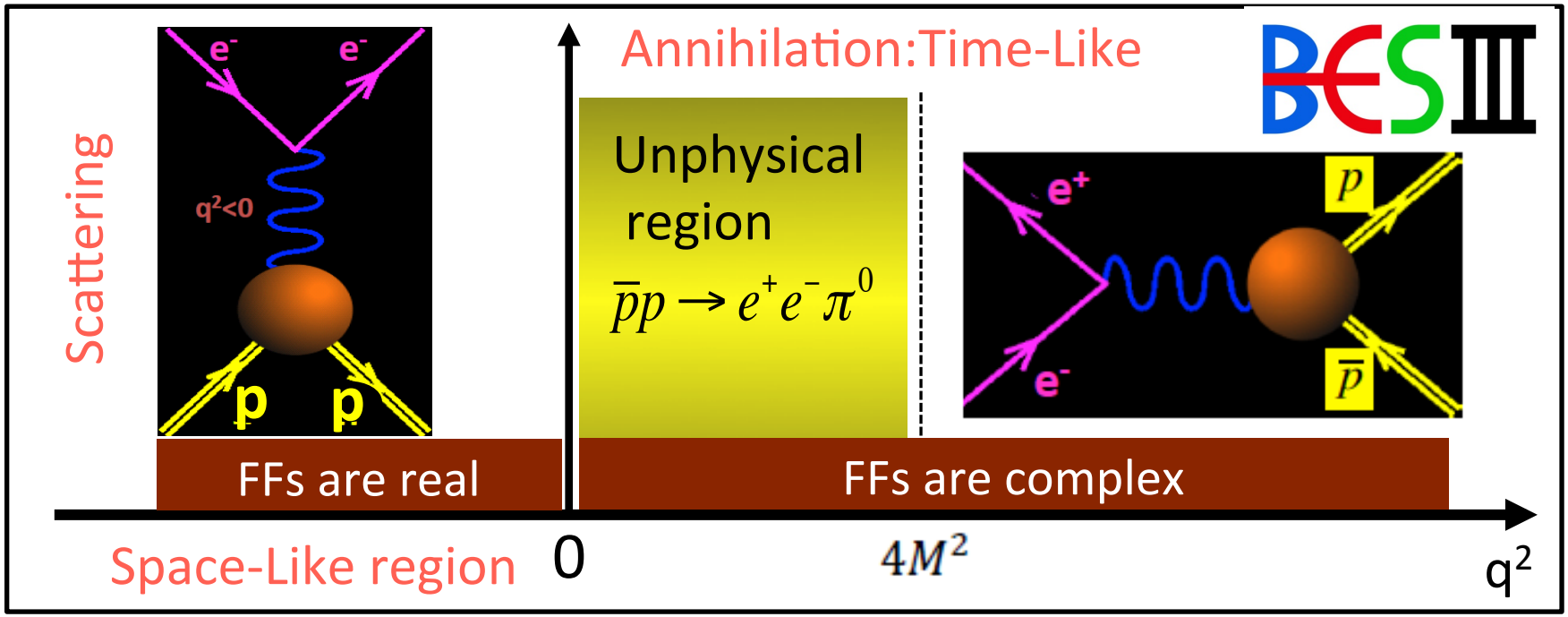
Crossing symmetry channels: - different kinematical regions
- observables are counterparts

Outline

Probing the structure of hadrons at BESIII by the annihilation of electron-positron beams of 1.0 - 2.3 GeV:

- BEPC-II and BESIII data
- Measurement of **proton electromagnetic form factors (FFs)** at BESIII using:
  - Scan technique: $e^+e^- \rightarrow p\bar{p}$
  - Initial state radiation (ISR) technique: $e^+e^- \rightarrow p\bar{p}\gamma$
- Measurement of **hyperon** FFs: $e^+e^- \rightarrow \Lambda_c^+\bar{\Lambda}_c^-, e^+e^- \rightarrow \Lambda\bar{\Lambda}$
- Ongoing analysis on the measurement of baryon FFs at BESIII
- Summary

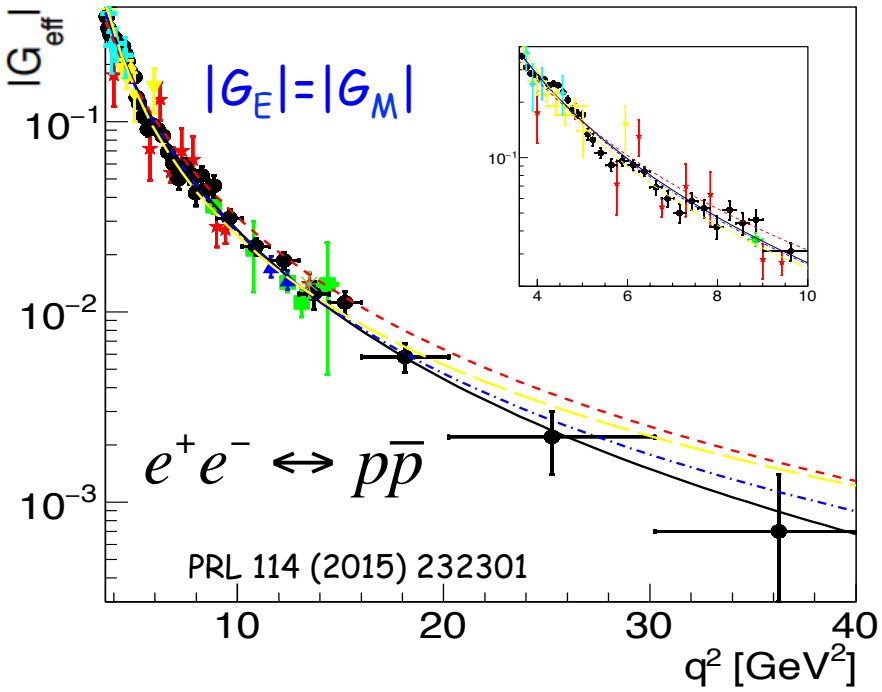
Proton electromagnetic FFs: the analyticity



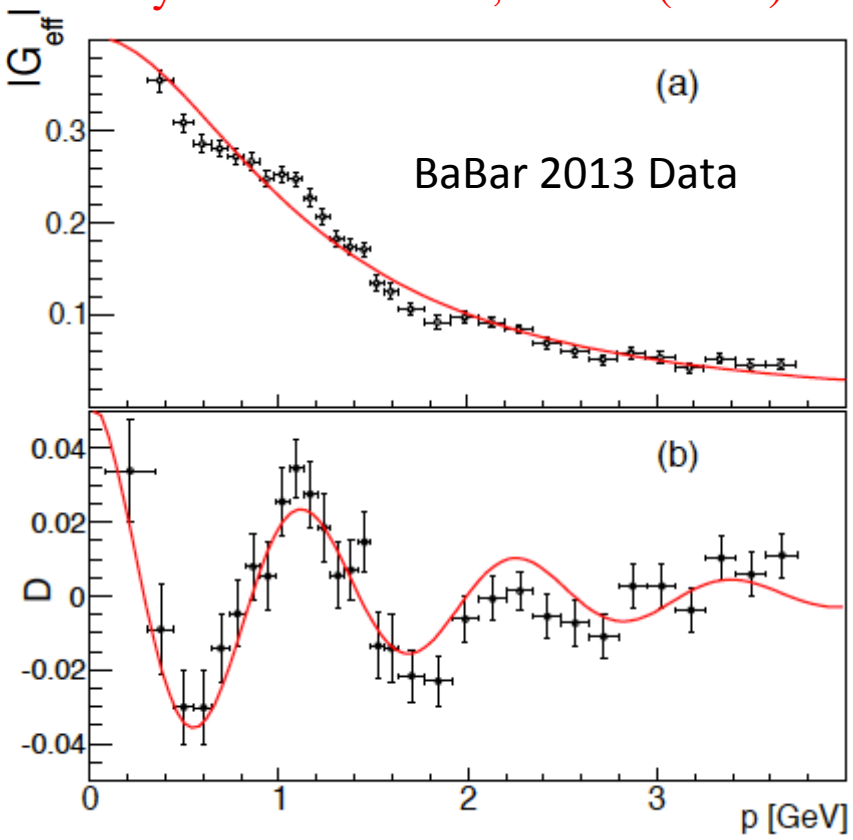
- **Electric G_E and magnetic G_M** proton FFs are analytical functions of the momentum transfer squared q^2

- Playground for theory and experiment:
  - at low q^2, probe the size of the nucleus,
  - at high q^2, test QCD scaling

Time-Like proton electromagnetic FFs

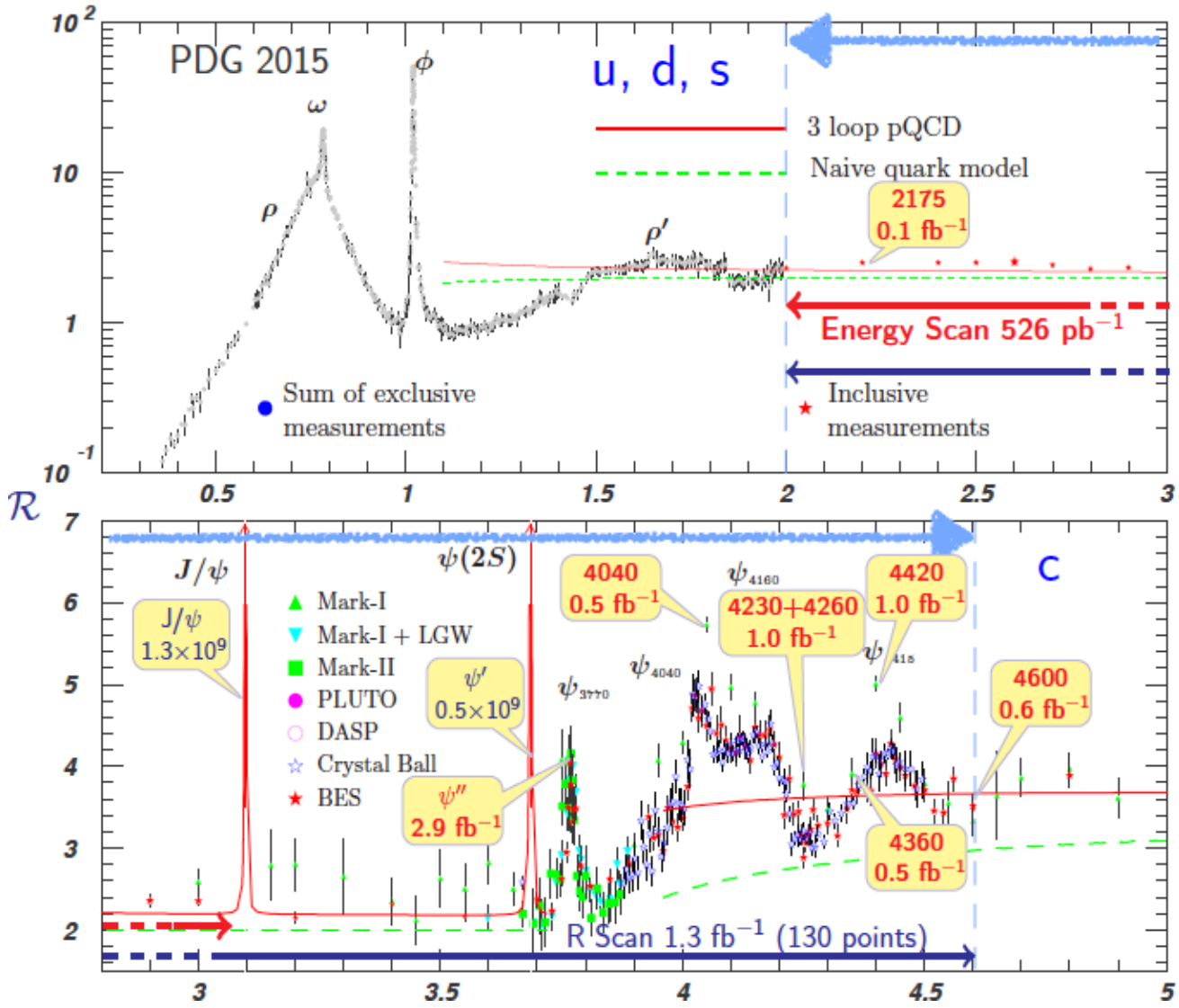


A. Bianconi, E. Tomasi-Gustafsson
Phys. Rev. Lett. 114,232301 (2015)

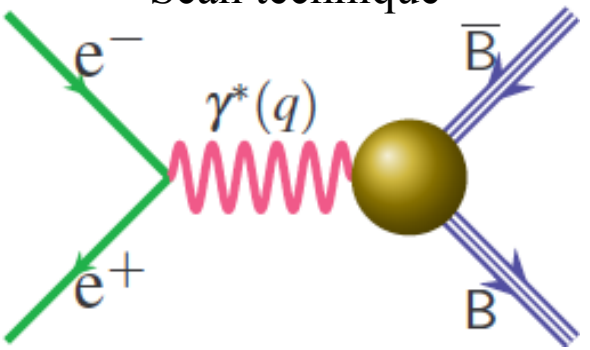


- No individual determination of G_E and G_M
- Steep behavior of the **effective FF (G_{eff})** at threshold
- Structures appeared in BaBar data (PRD 87 (2013) 092005)?

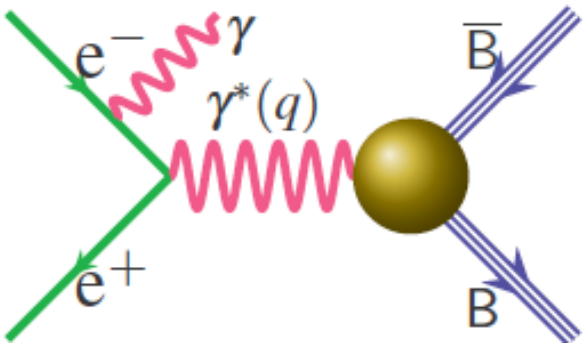
BESIII data samples



Scan technique

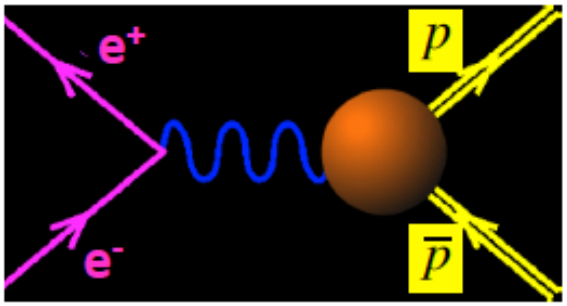


ISR technique

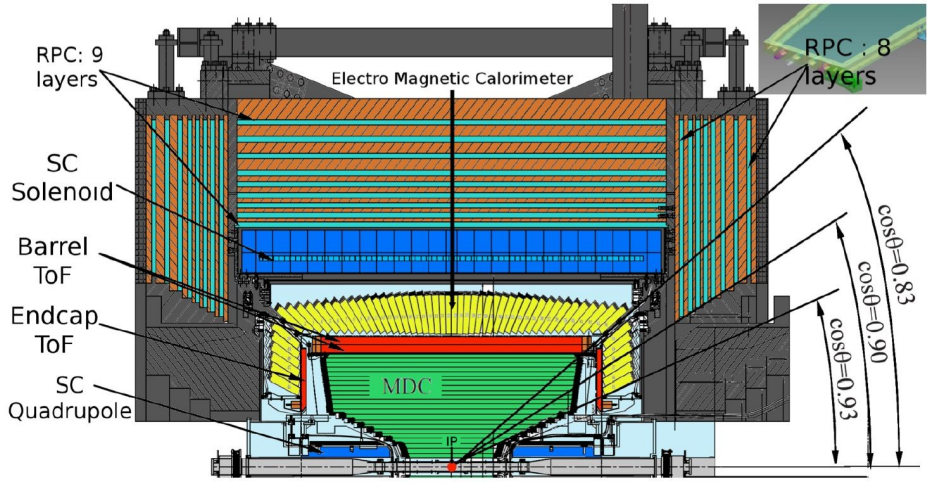


Measurement of $e^+e^- \to p\bar{p}$ at BESIII Phys. Rev. D91, 112004 (2015)

Based on **157 pb^{-1}** collected in **12 scan** points between **2.22 – 3.71 GeV** in 2011/2012:



- Beam associated background
- Physical background: charged lepton/meson pair production,
- *and* $e^+e^- \to p\bar{p}\pi^0, p\bar{p}\pi^0\pi^0, \Lambda\bar{\Lambda}$

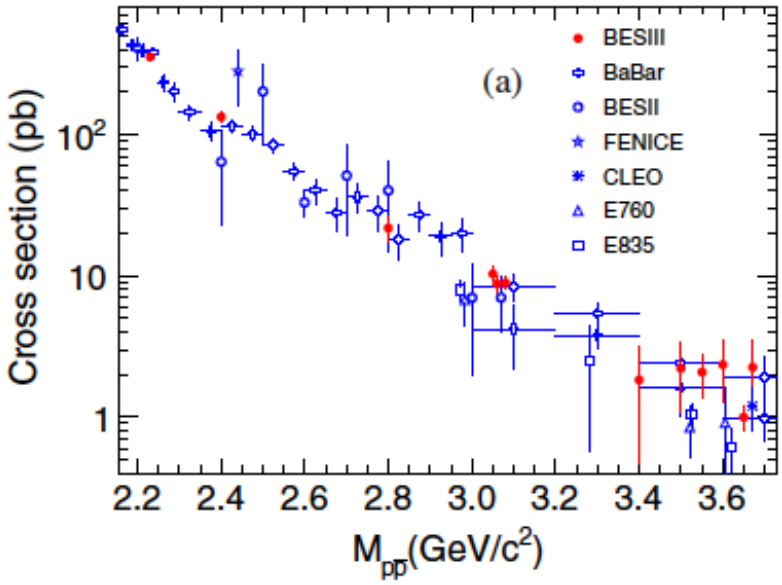


I. Charged tracks reconstructed by the MDC
II. Particle identification:
   - dE/dx and TOF (Prob(p) > Prob(K/ π)
   - Proton: $E_{EMC}/p<0.5$, $\cos\theta < 0.8$
III. Two charged tracks
   - back-to-back in c.m.s
   - Momentum constraints for p and pbar

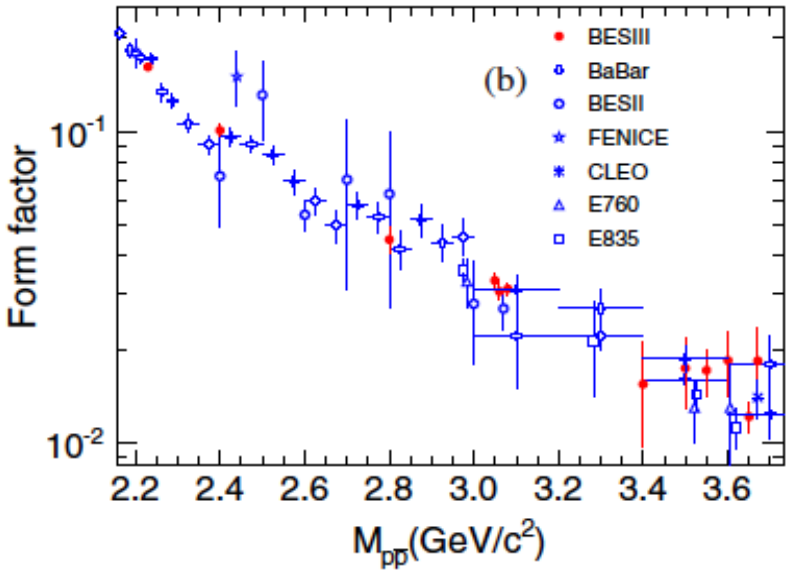
- Background negligible or subtracted
- Signal efficiency between 60% and 3%

Measurement of $e^+e^- \to p\bar{p}$ at BESIII Phys. Rev. D91, 112004 (2015)

(a) The Born cross section



(b) The effective FF ($|G_E|=|G_M|$)



$$\sigma_{Born} = \frac{N_{obs} - N_{bkg}}{L\varepsilon(1+\delta)}$$

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

N_{obs}: observed number of data

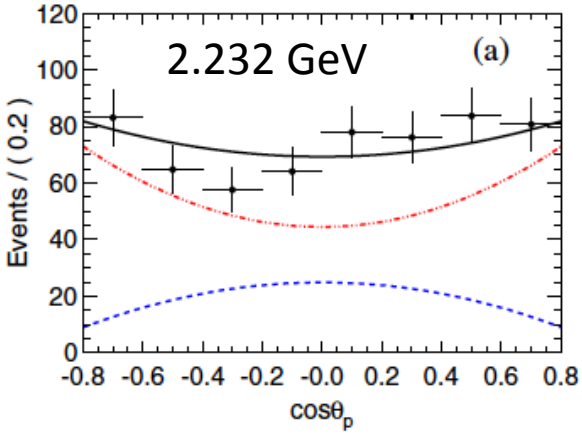
N_{bkg}: background evaluated from MC

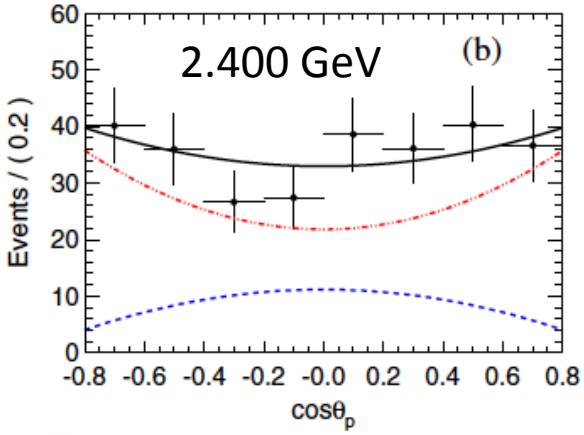
L: luminosity; ε: detection efficiency; (1+δ) and C: radiative and Coulomb correction factor

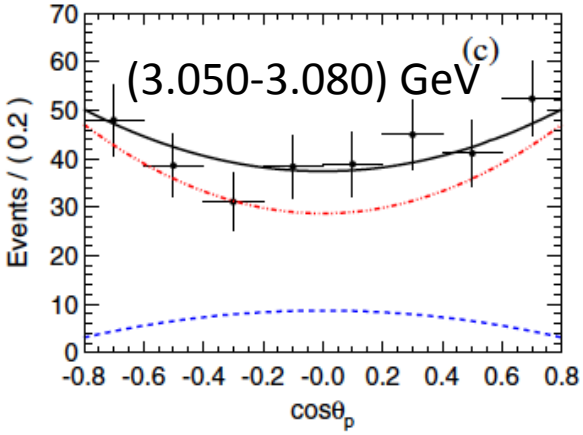
The measured born cross sections and the effective FFs are in good agreement with previous experiments, improving the overall uncertainty by ~30%

Measurement of $e^+e^- \to p\bar{p}$ at BESIII Phys. Rev. D91, 112004 (2015)

Extraction of the electromagnetic $R=|G_E|/|G_M|$ ratio

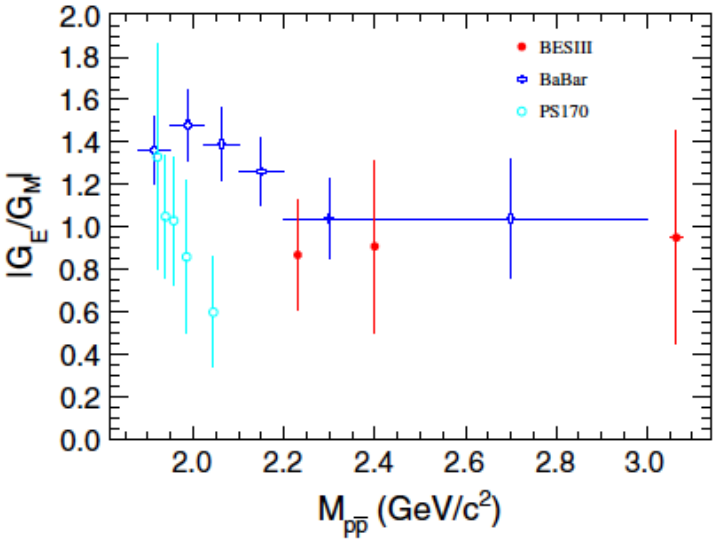




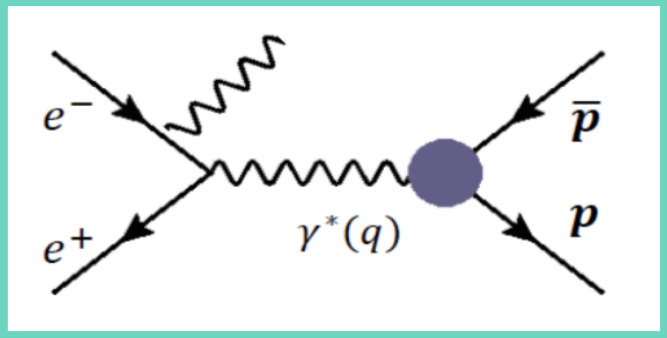


$$\frac{dN}{d\cos\theta_p} = N_{norm}\left[(1+\cos^2\theta_p) + R^2 \ \frac{1}{\tau}\sin^2\theta_p\right]$$

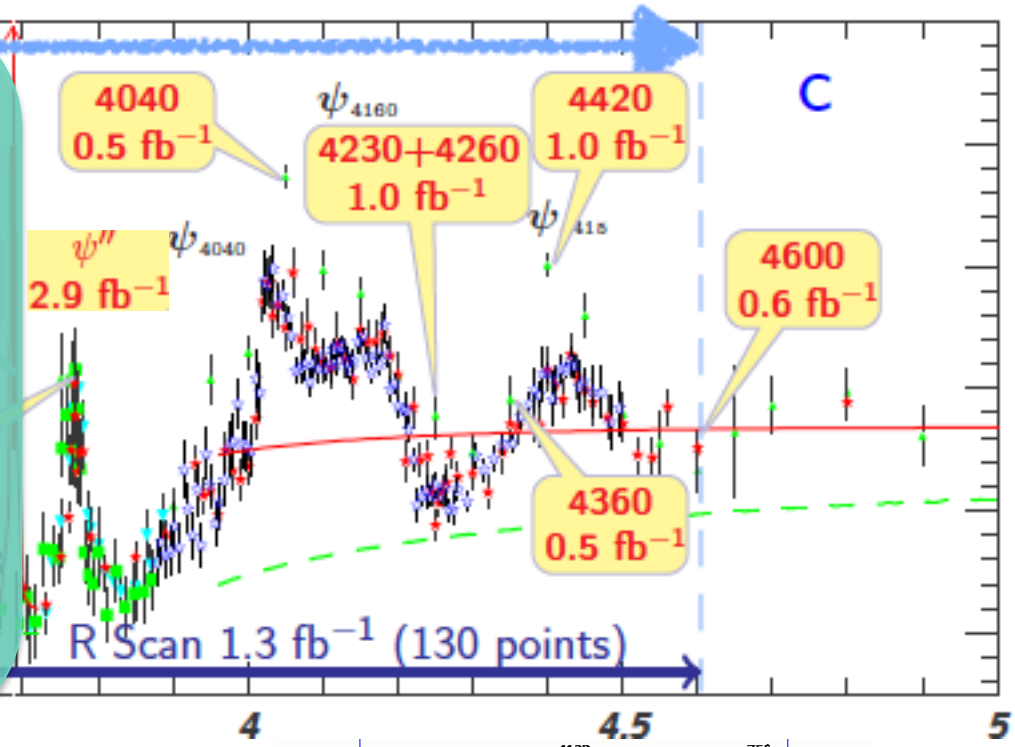
$\sqrt{s}$ (MeV)	$\lvert G_M\rvert$ ($\times 10^{-2}$)
	Fit on $\cos\theta_p$
2232.4	$18.42 \pm 5.09 \pm 0.98$
2400.0	$11.30 \pm 4.73 \pm 1.53$
(3050.0, 3080.0)	$3.61 \pm 1.71 \pm 0.82$



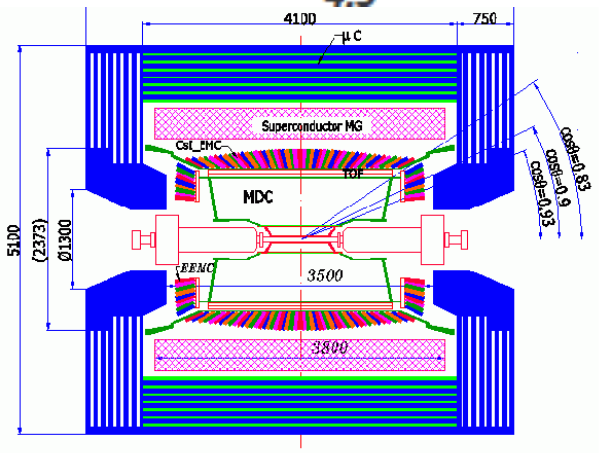
Measurement of proton FFs with ISR technique



Based on **7.4 fb^{-1}** collected @ ψ(3770), ψ(4040), Y(4230), Y(4260), Y(4360), Y(4420), Y(4600)



- Continuous q^2-range is available from the threshold
- Angular distribution (FF ratio) and effective FF measurements
- Tagged + untagged ISR photon analysis



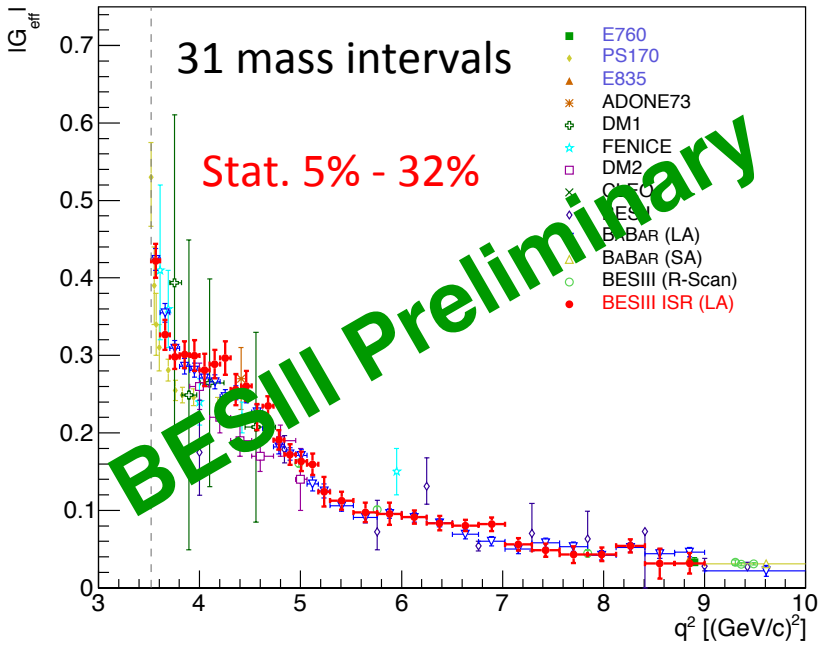
Measurement of proton FFs with tagged ISR technique

Event selection: $e^+e^- \to p\bar{p}\gamma$

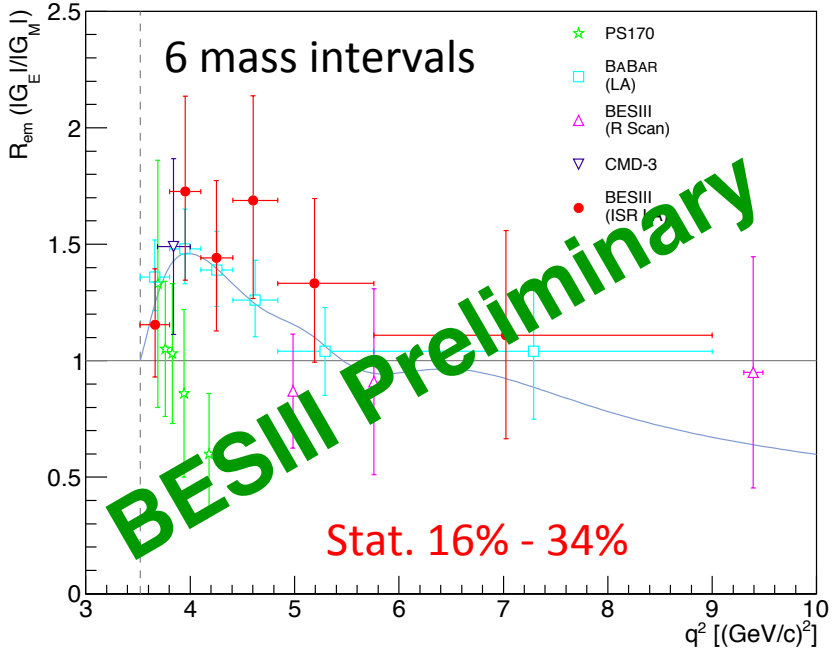
- Two charged tracks from vertex
- One high energy shower in EMC (Tagged ISR)
- Kinematic constraints applied
- Background evaluation and subtraction

- Combine the seven data samples (7.4 fb^{-1})
- The proton FFs extracted between the threshold and 3.0 GeV
- Systematic uncertainty included

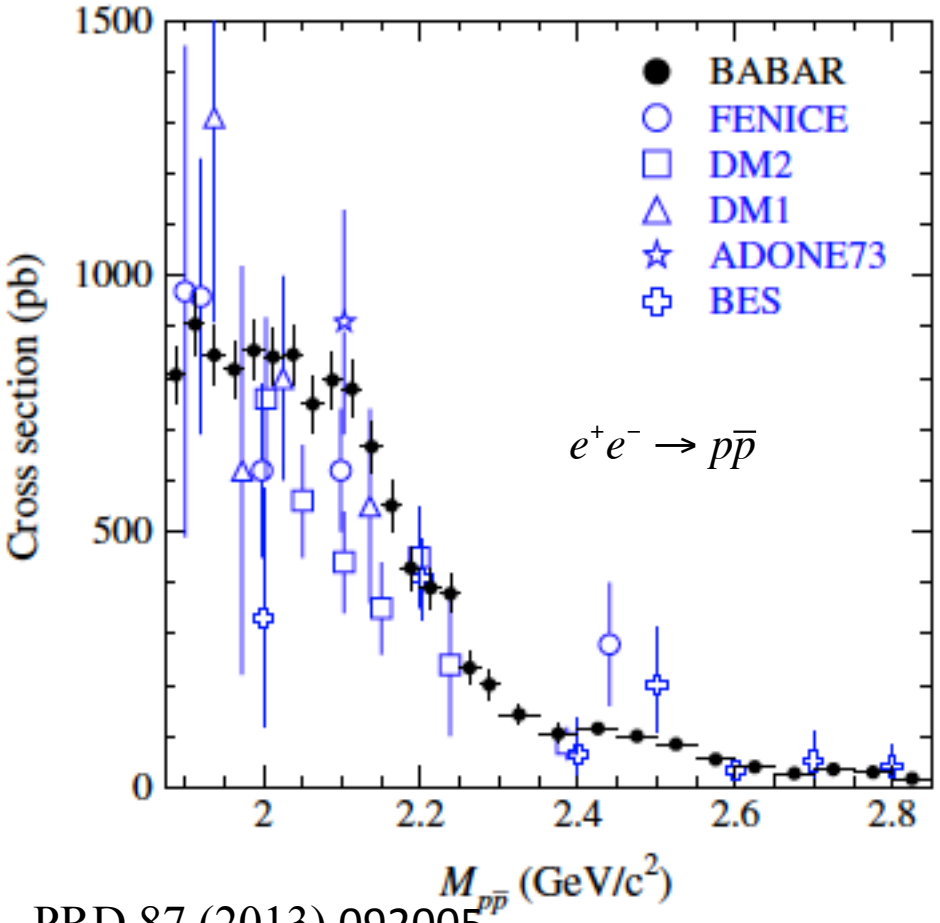
Proton effective FF



Proton FF ratio



Baryon pair production: unexpected behavior near threshold



PRD 87 (2013) 092005

- Annihilation cross section

$$\sigma_{e^+e^-\to B\bar{B}} = \frac{4\pi\alpha^2\beta}{3q^2} C \left[\left|G_M(q^2)\right|^2 + \frac{1}{2}\left|G_E(q^2)\right|^2 \right]$$

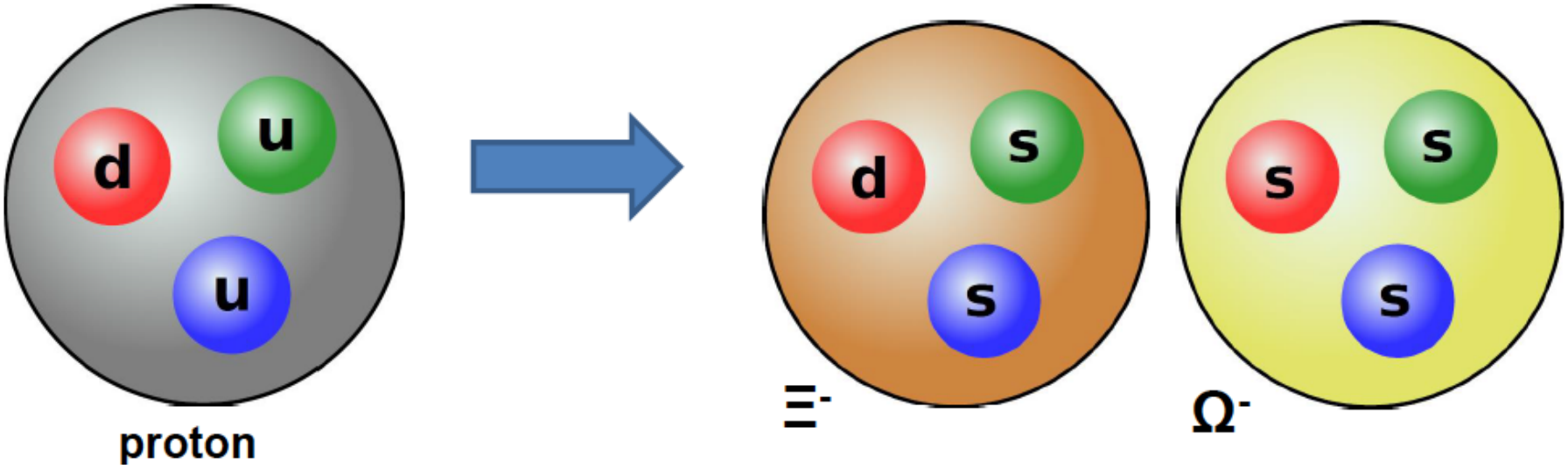
$\beta = \sqrt{1 - 4M_B^2/q^2}$ and C is the Coulomb factor

- Strong energy dependence near threshold with other charged baryons?
- Cross section for neutral baryon production near threshold?

Electromagnetic form factors of Hyperons

Hyperon pair production:

Possibility to be much closer to the threshold than the proton case with a direct production

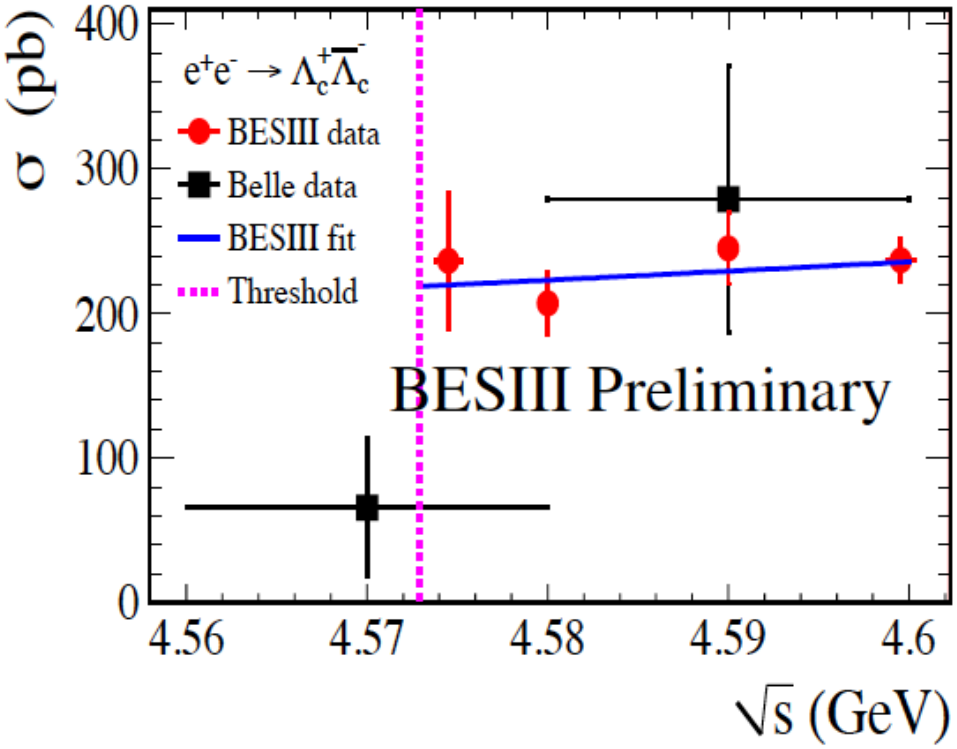


Cross section measurement of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ at BESIII

BESIII has collected in 2014 significant data sample close to the Λ_c threshold:

$$e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$$

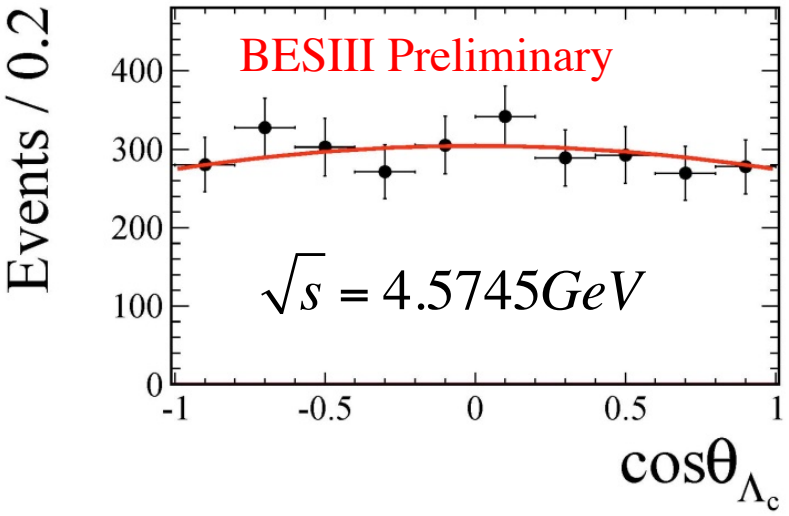
$\sqrt{s}$ [GeV]	Luminosity [pb^{-1}]
4.5745	47.67
4.580	8.545
4.590	8.162
4.5995	566.9

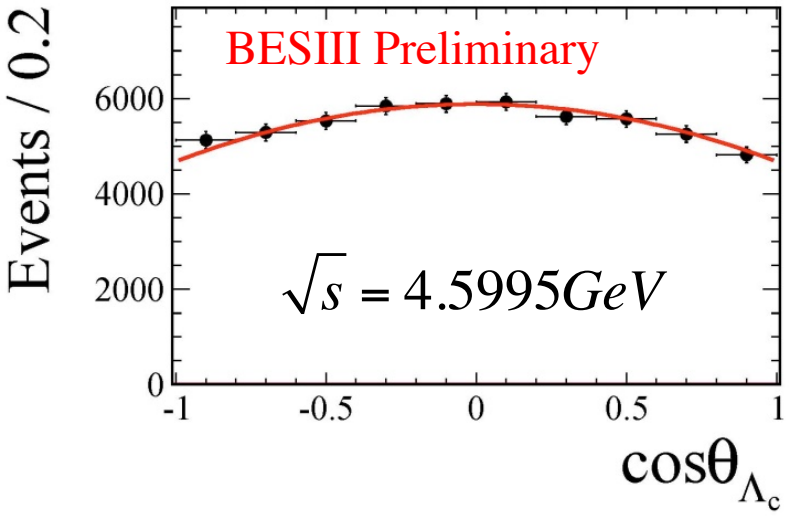


- First direct measurement of Λ_c form factors
- Data are very close to threshold
- Measurement of the Born cross section at 4 energy points below 4.6 GeV with **unprecedented statistical accuracy** (~1.3% at 4.6 GeV)
- **Possible determination** of the Λ_c FF ratio at 4.57 and 4.6 GeV

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

Measurement of the angular distributions at center of mass energies 4.5745 and 4.5995 GeV:





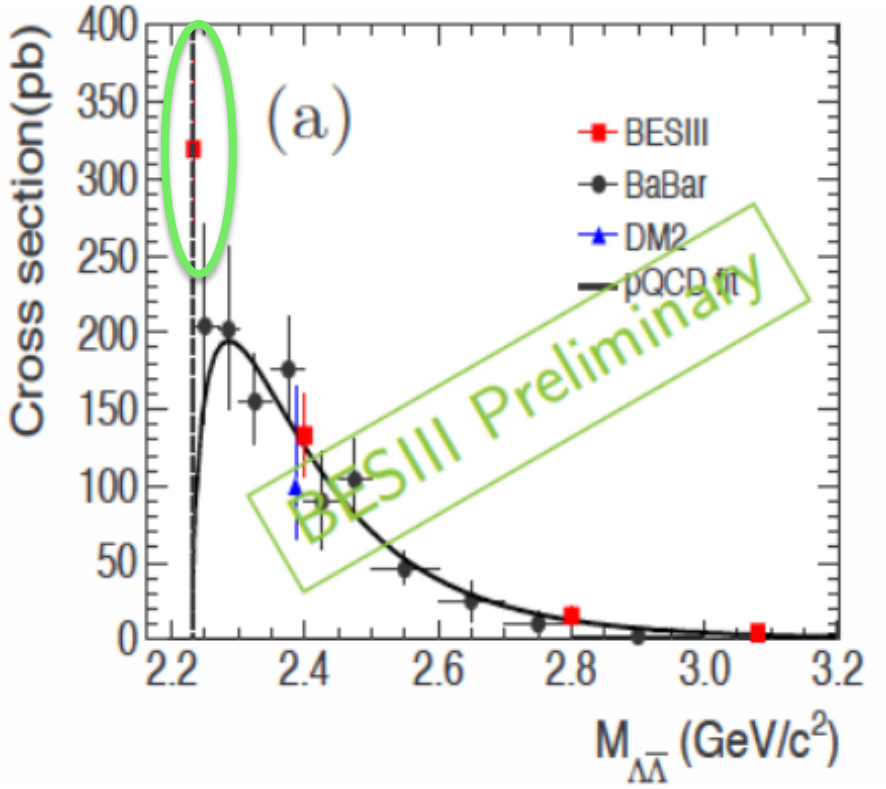
First time measurement of the Λ_c^+ form factor ratio

$\sqrt{s}$ [GeV]	Luminosity [pb^{-1}]	$\lvert G_E \rvert / \lvert G_M \rvert$
4.5745	47.67	1.14 ± 0.14 ± 0.07
4.580	8.545	
4.590	8.162	
4.5995	566.9	1.23 ± 0.05 ± 0.03

Cross section measurement of $e^+e^- \to \Lambda\bar{\Lambda}$ at BESIII

Based on **40.5 pb^{-1}** collected in 4 scan points between **2.2324 – 3.08 GeV** in 2012:

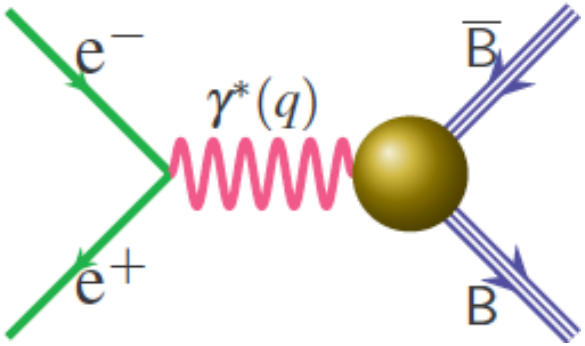
$\sqrt{s}$ (GeV)	Channel
2.2324	$\Lambda \to p\pi^-, \bar{\Lambda} \to \bar{p}\pi^+$
	$\bar{\Lambda} \to \bar{n}\pi^0$
	combined
2.4000	$\Lambda \to p\pi^-, \bar{\Lambda} \to \bar{p}\pi^+$
2.8000	
3.0800	

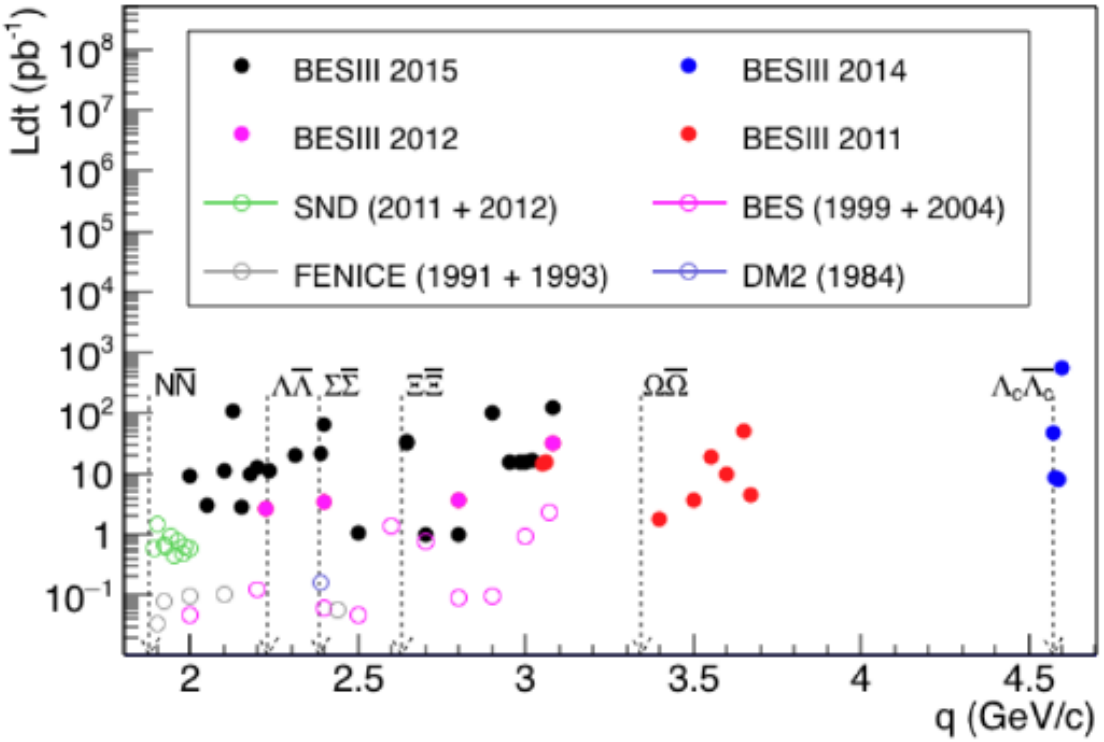


- Non-zero behavior at threshold: in theory Coulomb correction is not considered
- Results are consistent with previous measurements: precision improved by 10%

Prospects: New energy scan 2015

Scan data 2015 between 2 and 3.08 GeV (552 pb^{-1})



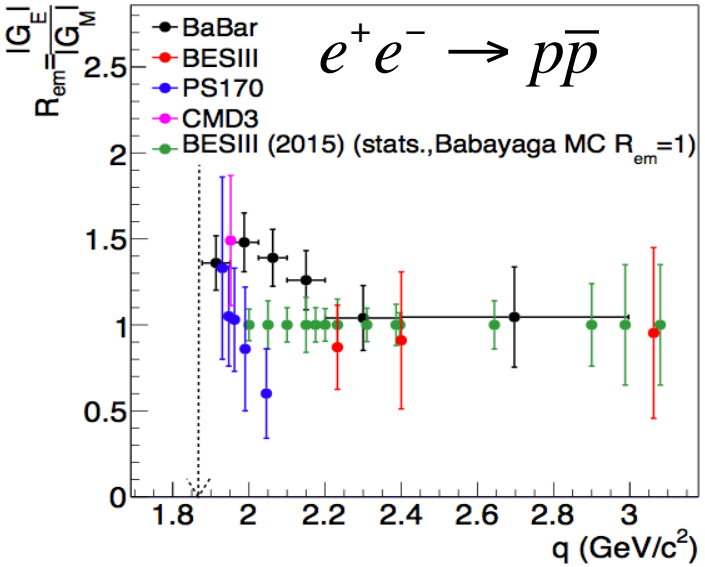


Unprecedented determination of baryons (proton, neutron, hyperons) form factors with a direct production of baryon pairs

Prospects: New energy scan 2015

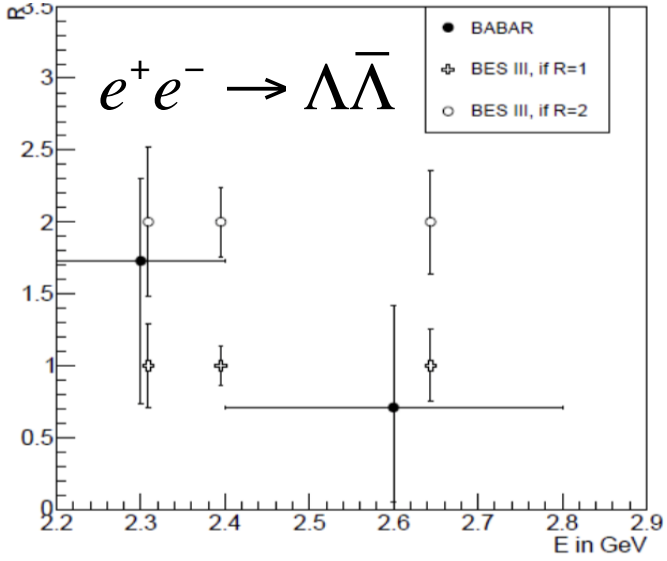
Proton form factors

- Precise measurement of proton FFs ($|G_M|$ and $|G_E|$) in narrow q^2-bins
- Expected (MC) statistical accuracies on $R=|G_E|/|G_M|=1$, between 9 % and 35%



Λ form factors:

- 6 points between 2.23 -2.9 GeV: unprecedented data samples.
- First determination of the ralative phase ϕ between G_E and G_M at 2.396 GeV
- Enough statistics at 4 energy points to extract $R=|G_E|/|G_M|$



Summary

- The **proton FFs** are measured at 12 c.m. energies based on 2012 scan data:
  - The effective FF measurements are in good agreement with previous experiments, improving the overall uncertainty by ~30%.
  - The **$|G_E|/|G_M|$ ratio** is extracted at three energy points, with uncertainty in 25% and 50% (dominated by statistics).

- Preliminary results on the proton FF measurement from the tagged-ISR analysis have been shown. Untagged ISR analysis is also ongoing.

- Preliminary results on Λ FF measurement based on 2012 scan data have been also shown

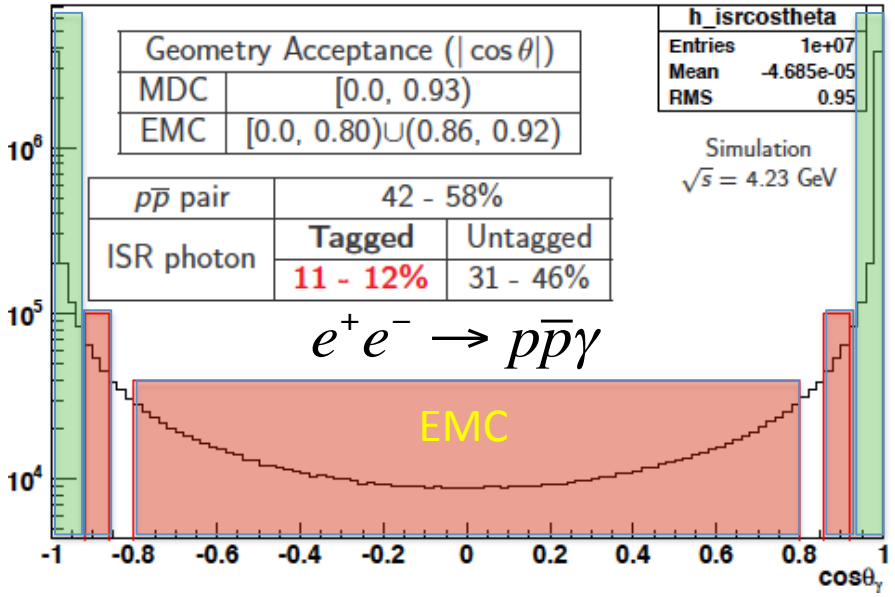
- First measurement of **Λ_c FFs (effective FF and FF ratio) in** direct baryon pair production

- **The measurements of baryon FFs will be significantly improved with the 2015 energy scan data from 2.0 GeV to 3.08 GeV**

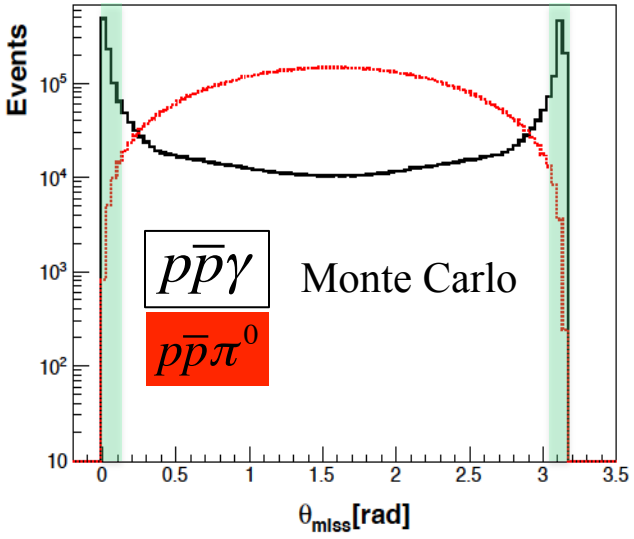
Thank you for your attention

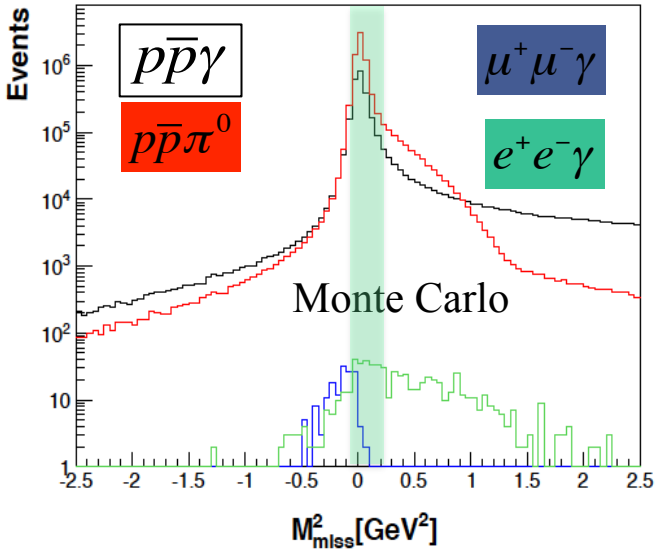
Back-up slides

Measurement of proton FFs with **untagged ISR technique**

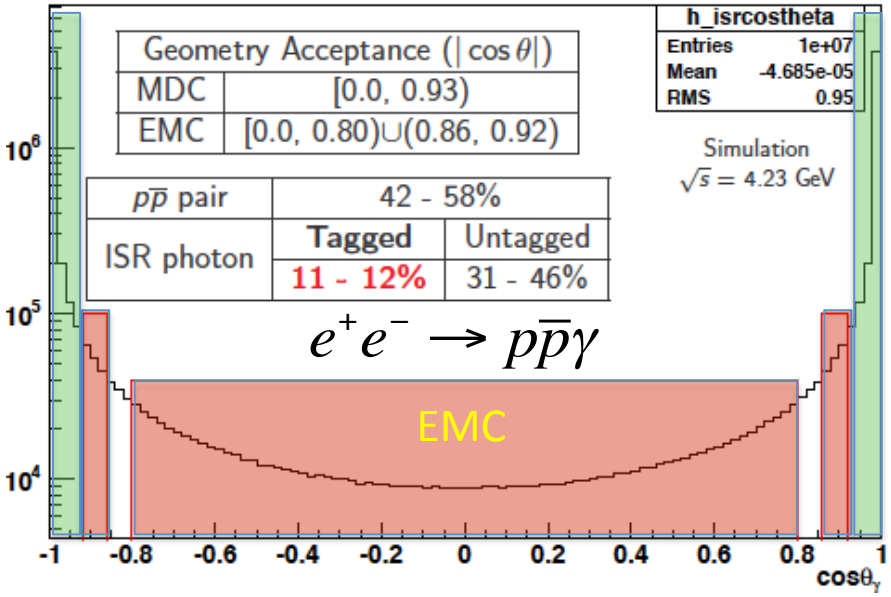


- Event selection (untagged analysis)
  - **Two charged tracks**
  - Identification of the non detected ISR-photon based on the distributions of the **missing momentum** and the **missing mass squared**.
- Background channels are almost suppressed
- Signal efficiency ~16%





Measurement of proton FFs with **untagged ISR technique**



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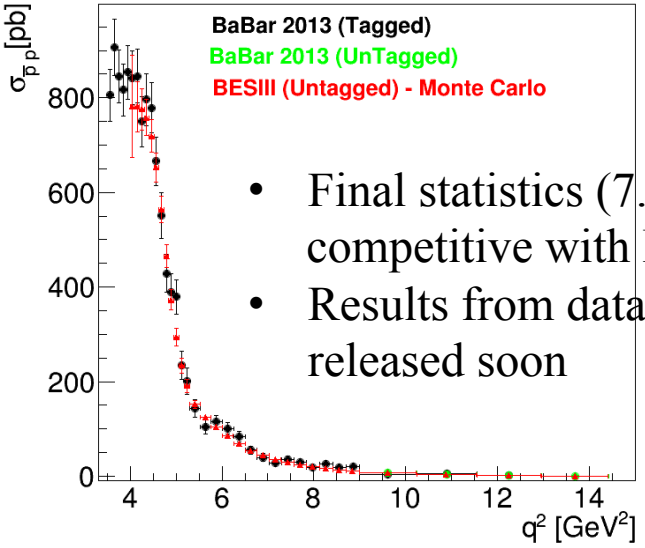
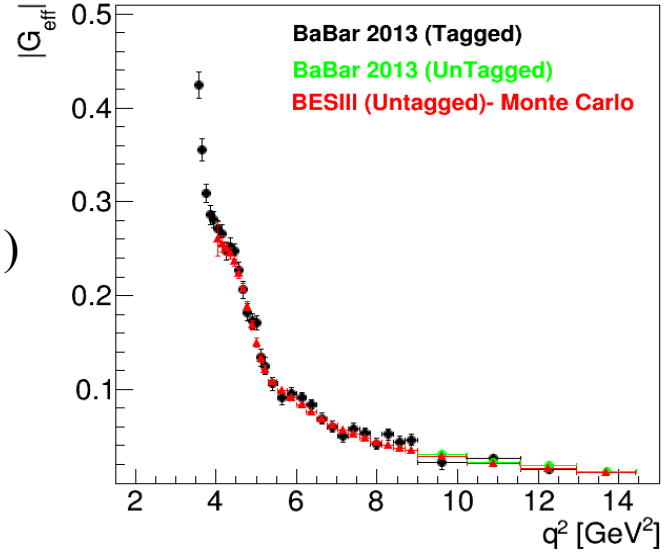


- Final statistics (7.4 fb^{-1}) are competitive with BaBar (469 fb^{-1})
- Results from data will be released soon

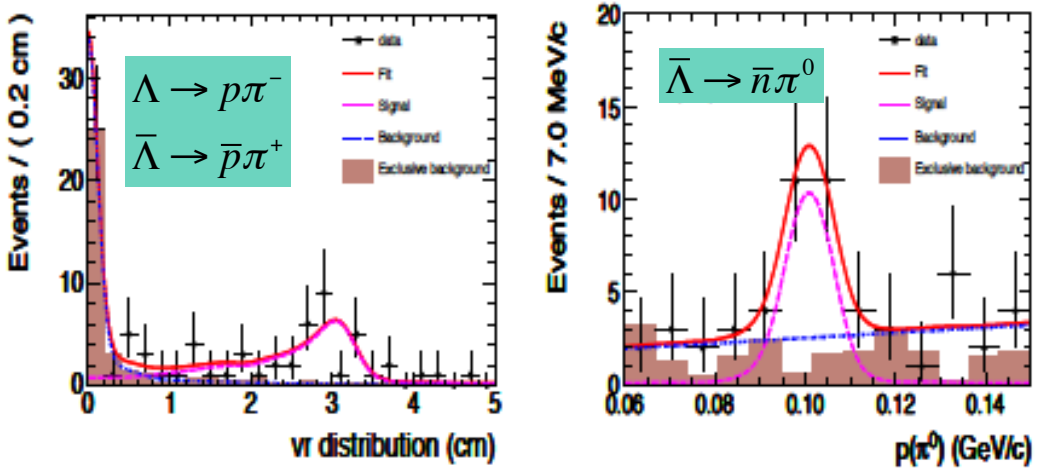


Cross section measurement of $e^+e^- \to \Lambda\bar{\Lambda}$ at BESIII

Based on **40.5 pb^{-1}** collected in 4 scan points between **2.2324 – 3.08 GeV** in 2012:

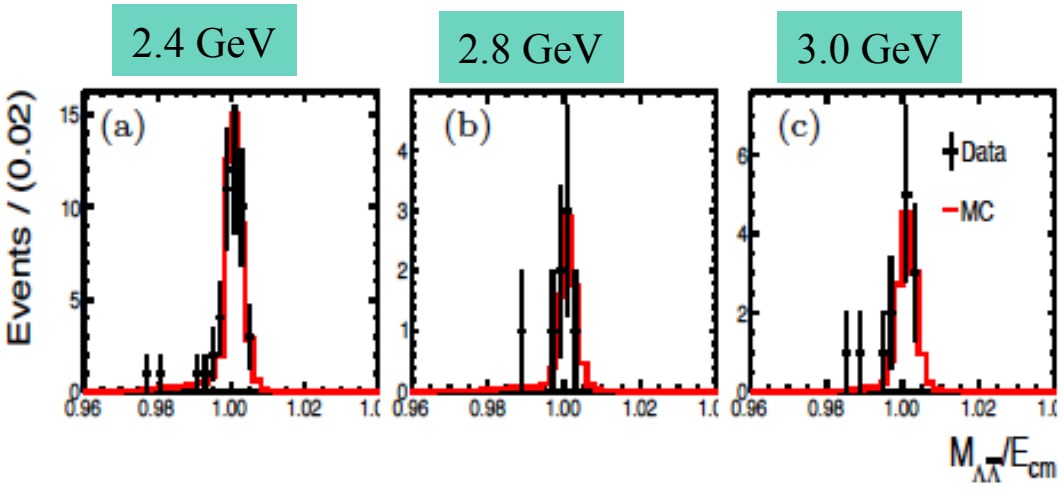
$\sqrt{s}$ (GeV)	Channel
2.2324	$\Lambda \to p\pi^-, \bar{\Lambda} \to \bar{p}\pi^+$ $\bar{\Lambda} \to \bar{n}\pi^0$ combined
2.4000 2.8000 3.0800	$\Lambda \to p\pi^-, \bar{\Lambda} \to \bar{p}\pi^+$

2.2324 GeV (1 MeV from threshold)



$\bar{\Lambda} \to \bar{n}\pi^0$

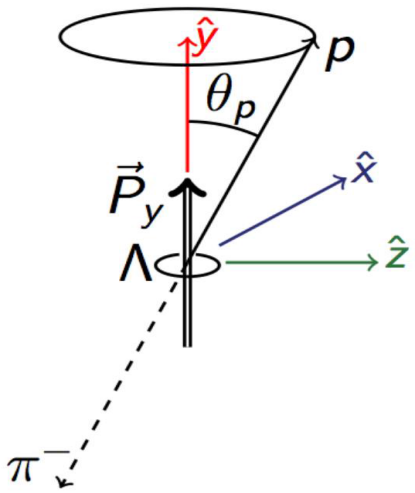
- Multiply Variable Analysis tool (Boosted Decision Tree)
- The final states of π^0 has a mono-momentum around 105 MeV.



Prospects: hyperon FFs at BESIII

Scan data 2015 between 2 and 3.08 GeV (552 pb^{-1})

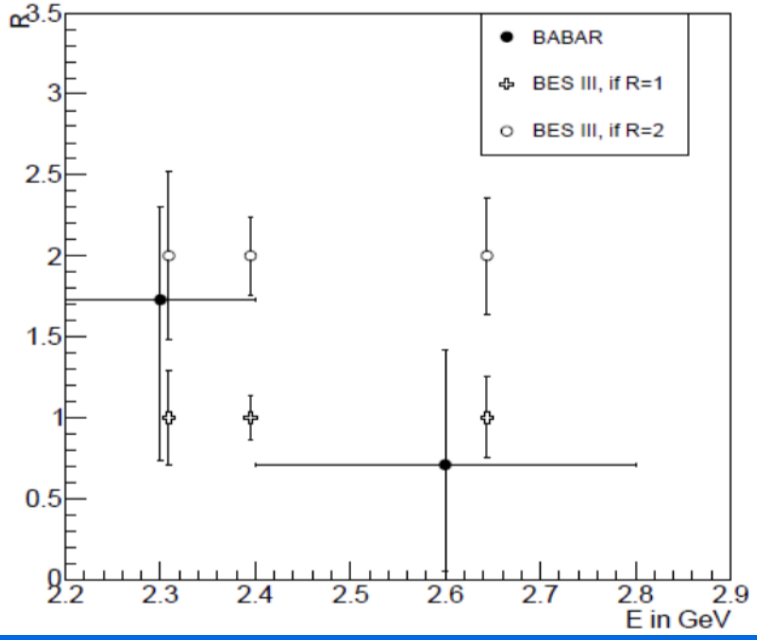
$e^+e^- \to \Lambda\bar{\Lambda}, \Lambda \to p\pi$



- Polarization is accessible thanks to the weak, parity violating decay: $\frac{dN}{d\cos\theta_p} \propto 1 + \alpha_\Lambda P_n \cos\theta_p$

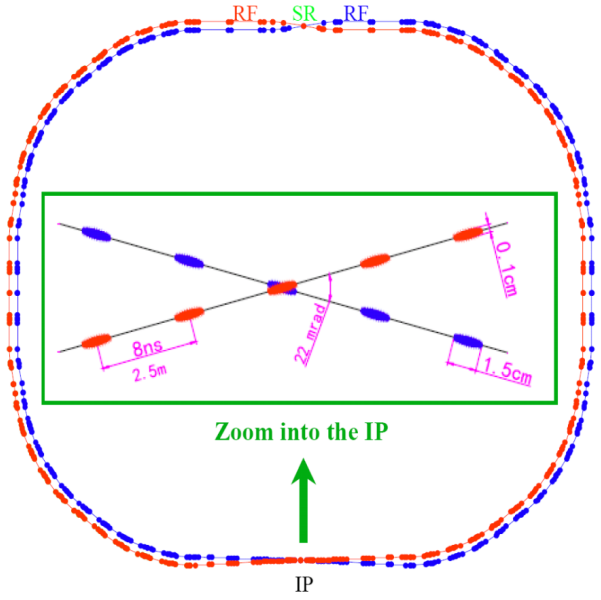
$$P_n = -\frac{\sin 2\theta \sin\Delta\phi / \tau}{R\sin^2\theta_\Lambda/\tau + (1+\cos^2\theta_\Lambda)/R} = \frac{3}{\alpha_\Lambda}\langle\cos\theta_p\rangle$$

- First determination of the ralative phase ϕ between G_E andG_M
- Enough statistics at 4 energy points to extract $R=|G_E|/|G_M|$
- Analysis are ongoing



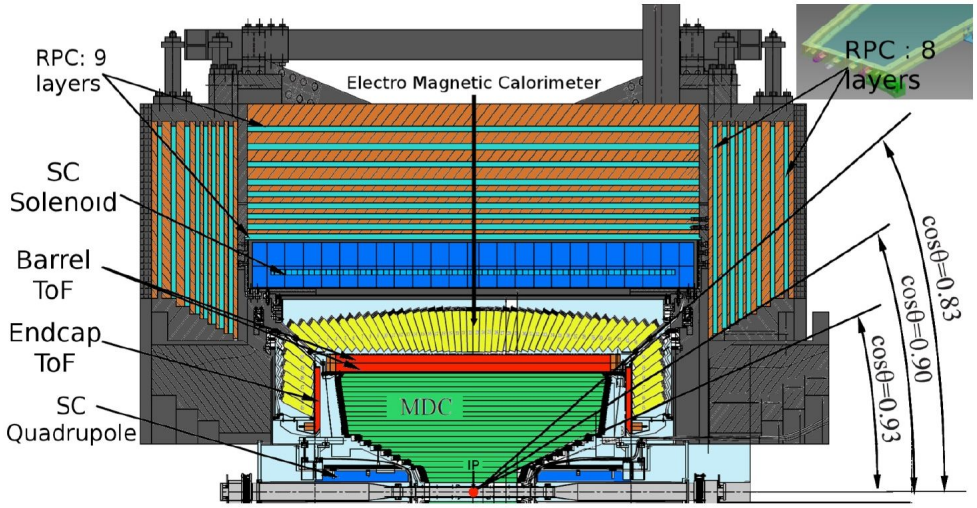
BEPC-II and BESIII detector

Beijing Electron Positron Collider



- Symmetric e^+e^- collider
- Beam energy: 1.0 - 2.3 GeV
- Optimum energy: 1.89 GeV
- Design luminosity: 10^{33} cm^{-2} s^{-1}
- Crossing angle: 22 mrad

BESIII detector



Electromagnetic Calorimeter
$\sigma_E/\sqrt{E}(\%)$=2.5% (1 GeV),
(CsI) $\sigma_{z,\phi}$(cm)=0.5-0.7 cm/$\sqrt{E}$

Muon Counter
σ_{xy}<2 cm

Time Of Flight
σ_T(barrel)=90 ps
σ_T(endcap)=110 ps

Main Drift Chamber
σ_{xy}=130 mm, dE/dx~6%
σ_p/p = 0.5% at 1 GeV