The Proton EM Form Factors Measurements from 2.0 – 3.1 GeV Energy Scan at BESIII

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(On Behalf of BESIII Collaboration)

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08–12.09.14, Frascati

$\overline{\text{P}}$ANDA L. Collaboration Meeting

Outline

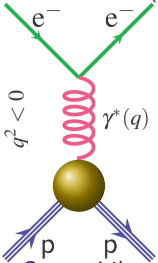
The Proton Electromagnetic Form Factors

- The **internal structure and dynamics** of the lightest baryon,
- The Form Factors in Space-Like(SL) region or Time-Like(TL) region,

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

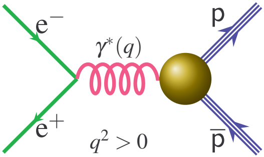
- The differential cross section for one photon exchange,

$$\frac{d\sigma}{d(cos\theta)} = \frac{\alpha^2\beta C}{4q^2}[|G_M|^2(1+cos^2\theta) + \frac{4m_p^2}{q^2}|G_E|^2 sin^2\theta]$$



Space-Like
FFs Real

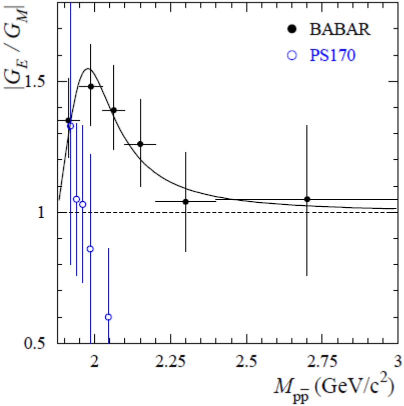
Form Factors	
Dirac:	$F_1(q^2)$
Pauli:	$F_2(q^2)$
$G_E = F_1 + \frac{\kappa q^2}{4M^2}F_2$	
$G_M = F_1 + \kappa F_2$	



Time-Like
FFs Complex

Data on Proton Time-Like Form Factor Ratio

PRD 87, 092005(2013)



$M_{p\bar{p}}$, GeV/c^2	N	N_{bkg}	$\|G_E/G_M\|$
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	$1.04^{+0.24+0.15}_{-0.25-0.15}$

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

$\Rightarrow$ **Inconsistent** between BaBar and PS170,

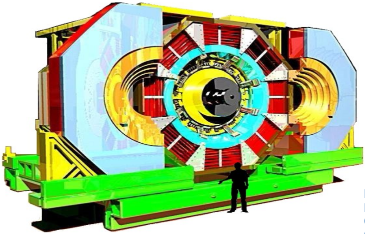
$\Rightarrow$ Maximum at 2 GeV/c^2,

$\Rightarrow$ Extraction of an effective FF based on assumptions,

$\Rightarrow$ 10%–24% statistics uncertainties.

Beijing Spectrometer III (BESIII)

BESIII @ BEPCII

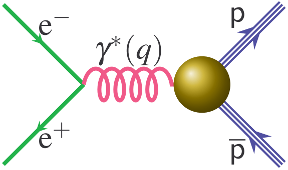


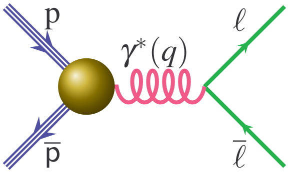
- Symmetric **e^-e^+ Collider**
- Crossing angle 22 mrad
- Beam energy: **1.0 - 2.3 GeV**
- Designed Luminosity: 10^{33} cm^{-1}s^{-1}
- Nearly 4π acceptance
- **Start of data taking: 2008**

BES-III Detector:
Electromagnetic Calorimeter, Main Drift Chamber, Time Of Flight system, Muon Chamber

More than **300 scientists (53 institutes)** from **16 countries** are involved in the BES-III Experiment. BES-III is located at the **Beijing Electron Positron Collider II (BEPCII).** The BEPCII has been in operation since 2008. One of the **recent achievements** was the **discovery of an unpredicted particle.**

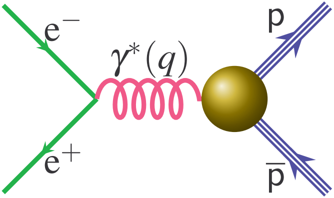
BESIII vs $\overline{\text{P}}$ANDA

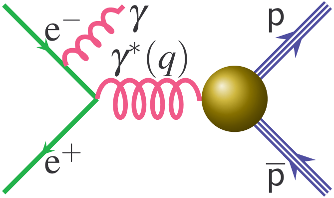




BESIII	$\overline{\text{P}}$ANDA
Energy scan + ISR method	Energy scan (e^+e^-or $\mu^+\mu^-$)
Possibility to access threshold	Large q^2 range ($\lvert\vec{P}_{\overline{p}}\rvert$: 1.5-15 GeV/c)
Neutron and proton FFs	Only proton FFs
-	Unphysical region ($e^+e^-\pi^0$)
-	Relative phase between G_E and G_M (polarised target)
Clean signal	Strong hadronic background

How to Measure the Form Factors at BESIII





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

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

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

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

The Status of Proton Form Factors Measurements at BESIII

Data samples for **ISR method** and **energy scan**.

Data Sample	$\mathcal{L}_{\text{int}}$	Energy Range	
J/Ψ	$\sim$0.45 fb^{-1}	3.097 GeV	
Ψ'	$\sim$0.8 fb^{-1}	3.686 GeV	
Ψ''	2.9 fb^{-1}	3.773 GeV	C. Morales, proton P. Larin, neutron
$\Psi(4040)$	0.5 fb^{-1}	4.009 GeV	
$Y(4260)$	1.9 fb^{-1}	4.23 and 4.26 GeV	D. X. Lin, proton
$Y(4360)$	0.5 fb^{-1}	4.36 GeV	A. Dbeyssi, proton untagged
$Y(4600)$	0.5 fb^{-1}	4.60 GeV	
Energy Scan	$\sim$12 pb^{-1}	2.23, 2.4, 2.8 and 3.4 GeV	X. R. Zhou, proton
	0.8 fb^{-1}	3.85 - 4.60 GeV	
	478 pb^{-1}	2.0 - 3.1 GeV	C. Rosner, proton

The data taking was approved in the summer collaboration meeting!

Preparatory Studies for the Low Energy Scan Proposal

- Low energy scan at BESIII: 2.0 GeV – 3.1 GeV,
- Integrated Luminosity: 478 pb^{-1}
- Multiply physics goals: proton, neutron, hyperon form factors, resonances and R vaules measuments,
- Detail MC simulation for proton form factors measuments,
  $\Leftarrow$ C. Morales *et al*.(HIM)
- Uncertainty estimate for hyperon form factors,
  $\Leftarrow$ K. Schönning(Uppsala)
- Groups involved: HIM, IHEP, INFN, JGU, Uppsala, USTC, ...

Proton Form Factors Preparatory Studies

To estimate luminoisties to achieve an accuracy in $R_{em}(=\frac{|G_E|}{|G_M|})$ around 10%.

- Use Babayaga_phase (P. Wang and M. Destefanis) as generator for $e^+e^- \to p\bar{p}$ with and w/o rad. corr.

$$\frac{d\sigma}{d\Omega}(q^2,\theta) = \frac{\alpha^2\beta C}{4q^2}|G_M|^2[(1+cos^2\theta) + R_{em}^2\frac{1}{\tau}sin^2\theta]$$

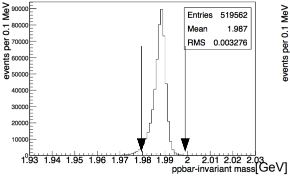
$\tau = \frac{q^2}{4m^2}$ and $|G_M| = 22.5(1+q^2/0.71)^{-2}(1+q^2/3.6)^{-1}$
(Eur. Phys. J. A44, 373(2010))

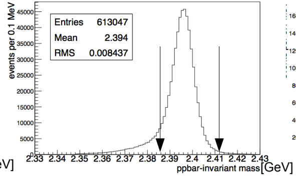
- 10^6 events generated for each bin between 2.0, 2.1, 2.1 ...3.0 GeV with and w/o ISR,
- Apply reconstruction routines to select $e^+e^- \to p\bar{p}$,
- Fit angular distribution on efficiency corrected MC data and study resulting resolutions in R_{em},

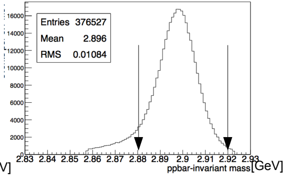
Reconstruction $e^+e^- \to p\bar{p}$

Ecm = 2.0 GeV | Ecm = 2.4 GeV | Ecm = 2.9 GeV

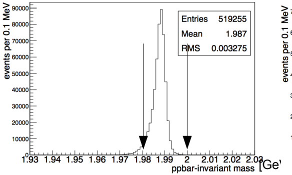
Babayaga_phase with ISR

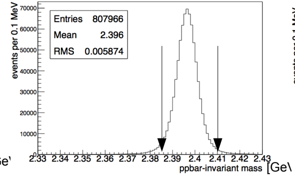


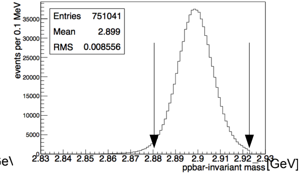




Babayaga_phase without ISR

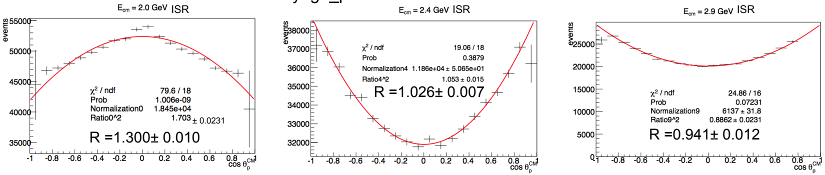




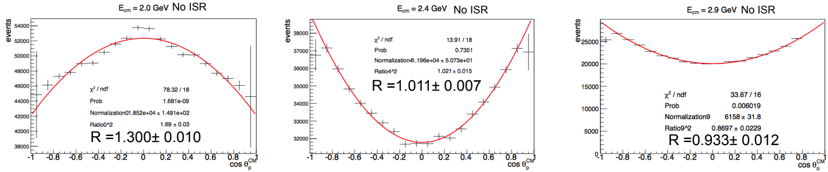


Radiative Effects in Angular Distribution Fit

Babayaga_phase with ISR



Babayaga_phase without ISR



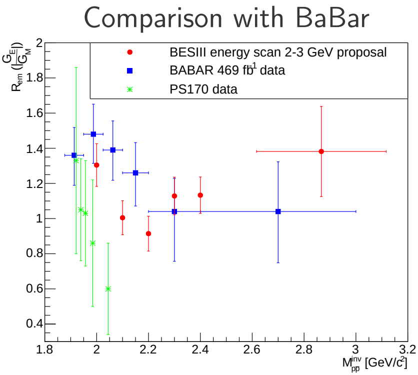
$$f(\cos\theta)=\text{Norm}[\tau(1+\cos^2\theta)+R^2_{em}(1-\cos^2\theta)]$$

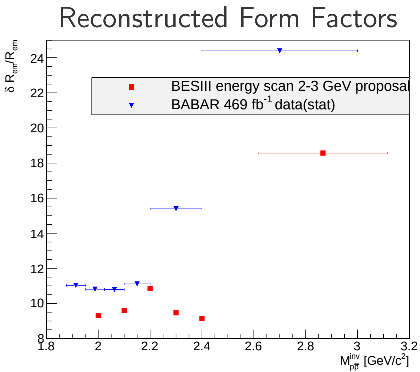
Proton Form Factors from Energy Scan Proposal Simulation

Time-Like (from proposal)								Space-Like	
		extracted from BOSS full simulation fits							
$M_{p\bar{p}}$	$\mathcal{L}$ (pb^{-1})	G_E	$\frac{\delta G_E}{G_E}$	G_M	$\frac{\delta G_M}{G_M}$	R_{em}	$\frac{\delta R_{em}}{R_{em}}$	$\sqrt{-q^2}$	$\frac{\delta R_{em}}{R_{em}}$
2.00	8.95	0.29	10.5%	0.22	4.8%	1.30	9.3%	1.99	10.8%
2.10	10.8	0.20	10.2%	0.20	3.4%	1.01	9.6%		
2.20	13.0	0.16	11.4%	0.17	3.1%	0.91	10.9%	2.18	13.9%
2.3084	20.0	0.14	10.0%	0.12	3.4%	1.13	9.5%	2.27	14.9%
2.3950	35.0	0.12	9.7%	0.10	3.1%	1.13	9.2%	2.35	31.9%
2.644	65.0	0.07	15.6%	0.07	5.2%	1.25	14.7%	2.59	32.1%
2.9	100.0	0.05	29.6%	0.04	8.5%	1.24	28.3%	2.91	129.7%
3.08	150.0	-	35.0%	-	8.5%	-	35.0%		

- The relative error for the last point, 3.08 GeV, is estimated based on the simulation of 2.9 GeV,
- To combine the last three energy points, 19% accuracy for R_{em} and G_E, and 6% accuracy for G_M would be achieved.
- **NEW**: accuracy in time-like region similar as for space-like.

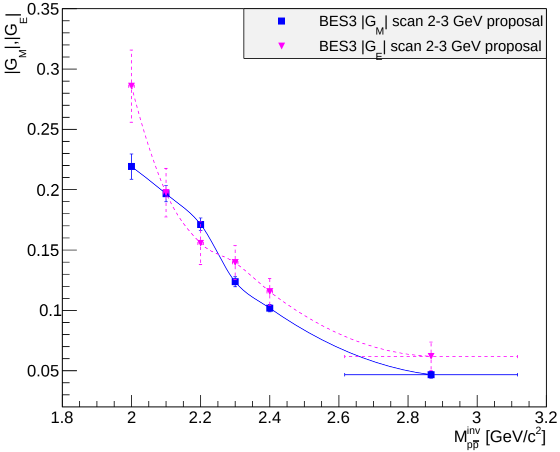
Comparison of Energy Scan Proposal with BaBar





* The last point in the plots is to combine the simulated energy points 2.644, 2.9 and 3.1 GeV.

Extract G_M and G_E Separately



Precise luminosity measurement at BESIII, it's possible to Extract $|G_M|$ and $|G_E|$ Separately.

Required Beam Time for the Proposed Data Taking

- The designed peak luminoisity at $\Psi''(3770)$,
- The luminosity decreased with the energy decreasing from optimized energy,

$$\mathcal{L} \propto E_{beam}^4$$

- Tuning time required by accelerator to achieve good status,
- Required beam time is 4 months (include tuning time) to take 478 pb^{-1} data.
- Data taking will be started in the end of this year.

Conclusions

- An accuracy between 9% - 15% can be achieved for the ratio (R_{em}) of the EM form factors of proton with the proposed low energy scan,
- To extract $|G_E|$ and $|G_M|$ without any asumption is possible with accuracies between 9% - 15% for $|G_E|$ and 4% - 9% for $|G_M|$,
- It's the first time to measure R_{em}, $|G_M|$ and $|G_E|$ in a wide energy range (2.0 to 3.10 GeV) in **very narrow q^2-bins**,
- Study of surprising structures in cross section is possible with **energy scan**,

Thank You for Your Attention!

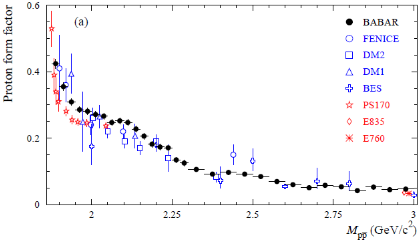
Backup

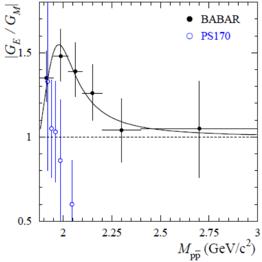
Proton Form Factors in Time-Like Region

- The differential cross section is written as a function of G_E(Electric) and G_M(Magnetic) for one photon exchange.

$$\frac{d\sigma}{d(cos\theta)} = \frac{\alpha^2 \beta C}{4q^2}[|G_M|^2(1 + cos^2\theta) + \frac{4m_p^2}{q^2}|G_E|^2 sin^2\theta]$$

- Previous experiments have been performed to measure the proton form factors with the assumption $|G_E| = |G_M|$. Only BaBar and PS170 have measured the **ratio** of electric to magnetic form factors.





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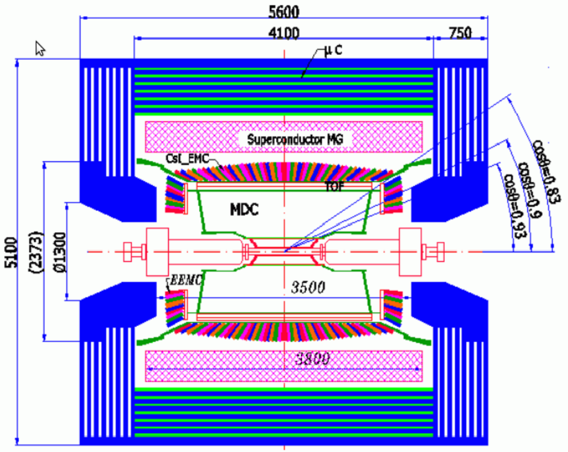
Beijing Spectrometer III (BESIII)



Beam Energy:
1.0 - 2.3 GeV
Crossing angle:
22 mrad
Designed Luminosity:
10^{33} cm^{-2}s^{-1}

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

TOF:
$\delta t = 100$ ps Barrel
$\delta t = 110$ ps Endcap

MUC:
$\delta(xy) <2$ cm

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