Measurements of Proton Electromagnetic Form Factors in Time-like Region at BESIII

Samer Ahmed, Alaa Dbeyssi, Paul Larin, <u>Dexu Lin</u>, Frank Maas, Cristina Morales, Christoph Rosner and Yadi Wang

1. Helmholtz-Institut Mainz

2. Johannes Gutenberg Universität

International School of Nuclear Physics 37th Course Probing Hadron Structure with Lepton and Hadron Beams

HELMHOLTZ









Sept. 16-24, 2015 Erice-Sicily

D.X. Lin (HIM)

Measurements of Proton Electromagnetic



1 Motivation and Introduction

2 The Measurements of Proton EM FFs with ISR Method

- 3 The Proton EM FFs from Energy Scan
- 4 Conclusions of Proton FFs Measurement

э

◆□ > → ● > → ● > → ● > →



2 The Measurements of Proton EM FFs with ISR Method

3 The Proton EM FFs from Energy Scan

4 Conclusions of Proton FFs Measurement

The Proton Electromagnetic Form Factors

- 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,



Data on Proton Time-Like Form Factor Ratio



Until to 2014

PRD 87, 092005(2013) Nucl. Phys. B 411, 3 (1994) ⇒ Only extraction of the ratio ^{|G_E|}/_{|G_M|},
 ⇒ Inconsistency between BaBar and PS170,
 ⇒ Maximum at 2 GeV/c²,
 ⇒ Extraction of an effective FF based on assumptions,
 ⇒ 10%-24% statistics uncertainties.

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

Beijing Spectrometer III (BESIII)





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**.

D.X. Lin (HIM)

Measurements of Proton Electromagnetic

୬ < ୍ୟ 6 / 20

How to Measure the Form Factors at BESIII





		,,, ,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,		
	Energy Scan	Initial State Radiation		
$E_{\textit{beam}}$	discrete	fixed		
L	low at each beam energy	high at one beam energy		
σ	$\frac{d\sigma_{p\bar{p}}}{d(\cos\theta)} = \frac{\pi\alpha^2\beta C}{2q^2} [G_M ^2 (1+\cos^2\theta)]$	$rac{d^2\sigma_{p\overline{p}\gamma}}{dq^2d heta_\gamma} = rac{1}{s}W(s,x, heta_\gamma)\sigma_{p\overline{p}}(q^2)$		
	$+\frac{4m_p^2}{q^2} G_E ^2\sin^2\theta]$	$W(s, x, heta_{\gamma}) = rac{lpha}{\pi^{\kappa}} (rac{2-2x+x^2}{\sin^2 heta_{\gamma}} - rac{x^2}{2})$		
q ² single at each beam energy from threshold to s				
Both techniques energy scan and initial state				

radiation, can be used at BESIII

D.X. Lin (HIM)

Measurements of Proton Electromagnetic

୬୯୯ 7 / 20

The Status of BESIII Data

Data samples for ISR method and energy scan.

Data Sample	\mathcal{L}_{int}	Energy Range (GeV)	Notes
J/Ψ	\sim 0.45 fb $^{-1}$	3.097	Large background contamination
Ψ'	${\sim}0.8~{ m fb}^{-1}$	3.686	Difficult to analyze
Ψ''	2.9 fb ⁻¹	3.773	n FFs
$\Psi(4040)$	$0.5 {\rm ~fb^{-1}}$	4.009	(tagged+untagged)
Y(4260)	$1.9 { m ~fb^{-1}}$	4.23 and 4.26	and n FFs
Y(4360)	$0.5 { m fb}^{-1}$	4.36	(tagged) with ISR
Y(4420)	$1.0 {\rm ~fb^{-1}}$	4.42	HIM
Y(4600)	$0.5 \ {\rm fb}^{-1}$	4.60	
	${\sim}12~{ m pb}^{-1}$	2.23, 2.4, (3.05, 3.08)	p+Λ FFs, USTC, Uppsala
Energy Scan	$0.8 { m ~fb^{-1}}$	3.85 - 4.60	R Scan
525.5 pl	525 5 nh^{-1}	2 00 - 3 08	Bayrons FFs, HIM,
	525.5 pb	2.00 - 3.00	USTC and Uppsala

Total luminosity above Ψ'' : 7.408 fb⁻¹.

D.X. Lin (HIM)

э



2 The Measurements of Proton EM FFs with ISR Method

3 The Proton EM FFs from Energy Scan

4 Conclusions of Proton FFs Measurement

・ロト ・ 同ト ・ ヨト ・ ヨト

The Analysis for Proton FFs with ISR Method at BESIII

- Data samples: 3.773, 4.009, 4.23, 4.26, 4.36, 4.42 and 4.60 GeV,
- Total luminosity: 7.408 fb⁻¹,
- Two analyses performed: ISR-Tagged (this talk) and ISR-Untagged,
 - ISR-Tagged: ISR photon detected in calorimeter,
 - ISR-Untagged: ISR photon escaped from the beam pipe,
- ISR-Tagged Analysis: Event selection
 - Two charged tracks with oposite charge identified as proton,
 - one high energy neutral shower in calorimeter,
 - 4-C kinematic fitting,
 - $p\overline{p}\pi^0$ event veto.
- Backgrounds Studies:
 - Inclusive $(q\overline{q})$ MC events,
 - **Exclusive** background: $p\overline{p}\pi^0$ events.

(人間) トイヨト イヨト

ISR-Tagged

ISR Photon Angular Distribution from 4230 MC Simulation

$\gamma_{_{\text{ISR}}}$ Angular Distribution



11 / 20

ISR-Tagged

pp Invariant Mass Spectrum from 4230 MC Simulation



Expected Events from the ISR-Tagged Analysis

The physics events for each data sample			
Data	Lum. (pb^{-1})	σ (pb)	\mathcal{N}^{phy}
3773	2917.00	6.74	19660
4040	481.96	5.54	2668
4230	1047.34	4.71	4931
4260	825.67	4.62	3812
4360	539.84	4.32	2331
4420	1028.89	4.16	4276
4600	566.93	3.73	2113

Based on MC Simulation with Phokhara 9.1

The expected events (Reconstructed) for different mass interval

Mass Interval	th 2.0	2.0 - 2.1	2.1 - 2.4	2.4 - 3.0
\mathcal{N}_{mass}^{exp}	683	572	875	388

Estimated Statistical Accuracy: ~20%

The Analysis is almost finished, and the publication will come soon!

D.X. Lin (HIM)



2) The Measurements of Proton EM FFs with ISR Method

3 The Proton EM FFs from Energy Scan

4 Conclusions of Proton FFs Measurement

イロト イポト イヨト イヨト

Energy Scan

The First Results of Proton FFs from R-Scan at BESIII

- R-Scan data in 2012, limited lunimosity.
- The First results of $e^+e^- \rightarrow p\overline{p}$ from R-Scan (PRD 91, 112004(2015)).
- To extract the Ratio (R_{em}) at 2.23, 2.4 and (3.05, 3.08) GeV.



Energy Scan from 2.0 - 3.08 GeV at BESIII (Proposal)

Time-Like (from proposal)				Spac	e-Like	
M _{pp}	$\mathcal{L} (pb^{-1})$	$\frac{\delta G_E}{G_F}$	$\frac{\delta G_M}{G_M}$	$\frac{\delta R_{em}}{R_{em}}$	$\sqrt{-q^2}$	$\frac{\delta R_{em}}{R_{em}}$
2.00	8.95	9.0%	3.0%	9.2%	1.99	10.8%
2.10	10.8	10.0%	3.0%	10.0%		
2.20	13.0	11.0%	3.0%	9.5%	2.18	13.9%
2.3084	20.0	10.0%	3.0%	9.7%	2.27	14.9%
2.3950	35.0	9.0%	3.0%	8.8%	2.35	31.9%
2.644	65.0	16.0%	5.0%	14.6%	2.59	32.1%
2.9	100.0	25.0%	6.0%	24.0%	2.91	129.7%
3.08	150.0	35.0%	8.5%	35.0%		

- Proposal studies with Babayaga (modification) Simulation,
- 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.
- Data taking was finished on May 2015. D.X. Lin (HIM) Measurements of Proton Electromagnetic 16 / 20

Energy Scan

Expected Accuracy of the Ratio $\binom{|G_E|}{|G_M|}$ from Energy Scan



The Status of Energy Scan

Energy range:	2.0 - 3.08 GeV
Data points:	21
Online Lumi.:	$525 \ \mathrm{pb}^{-1}$

Green points are MC Simulation for energy scan proposal study.

D.X. Lin (HIM)



2 The Measurements of Proton EM FFs with ISR Method

3 The Proton EM FFs from Energy Scan



・ロト ・ 同ト ・ ヨト ・ ヨト

Conclusions and Outlook

- Two methods to measure proton EM FFs at BESIII.
- ISR analyses (tagged and untagged) above 3.773 GeV are ongoing, and the results are expected very soon.
- The expected accuracy of R_{em} will be comparable with BaBar from ISR analysis.
- The first results of proton FFs from R-Scan was published in 2015.
- The Energy Scan (2.0 3.08 GeV) data was collected in 2015.
- Data analysis for proton FFs with Energy Scan is ongoing.
- It will be the first time to measure the R_{em} , $|G_E|$ and $|G_M|$ in a wide energy range in very **narrow** q²-bins.
- An accuracy between 9% 15% can be achieved for the ratio (R_{em}) with Energy Scan data.

・ロト ・ 同ト ・ ヨト ・ ヨト

Thank You for Your Attention!

э

(日) (四) (三) (三)