Measurements of Proton EM Form Factors in TL Region at BESIII

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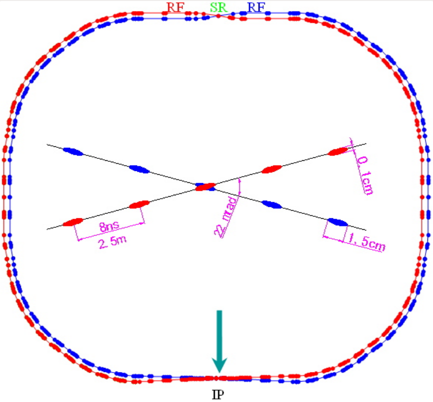
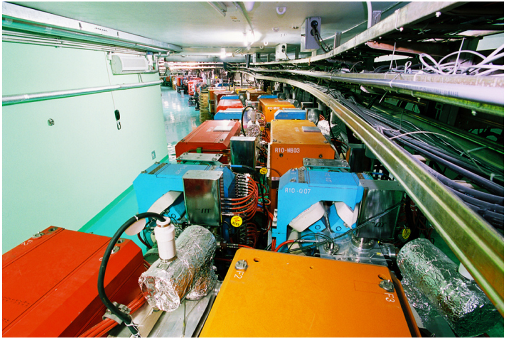
Outline

BEPCII and BESIII

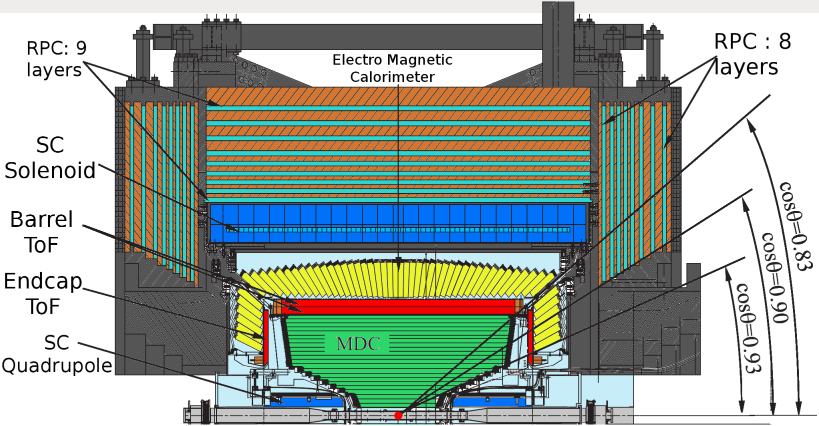
Double Storage Rings of BEPCII: A τ-charm factory





Beam energy:	1.0 - 2.3 GeV	Beam current:	0.91 A
Optimum energy:	1.89 GeV	Designed Lumi:	1×10^{33} cm^{-2}s^{-1}
Crossing Angle:	$\pm$11 mrad	Achieved time:	5th April, 2016

BESIII Spectrometer



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

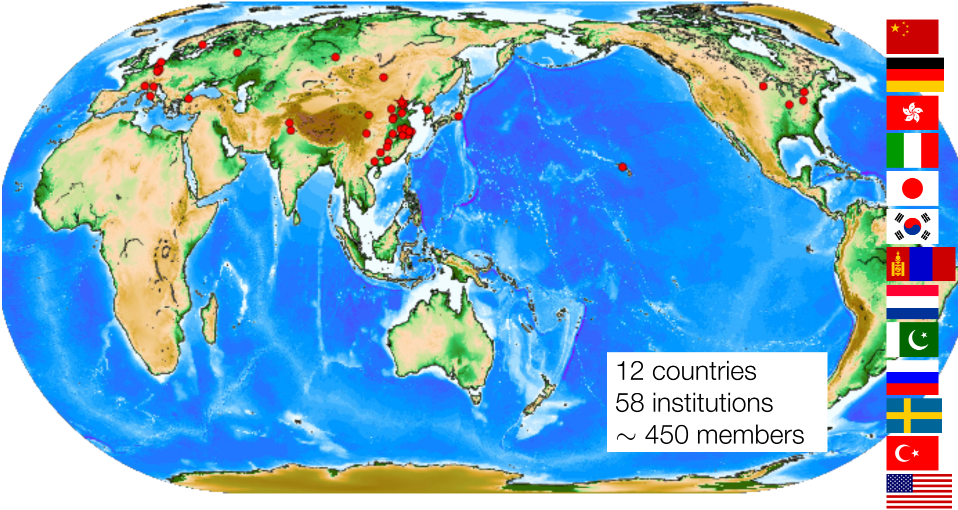
TOF
δt 80 ps Barrel
δt 110 ps Endcap

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

MUC
$\delta(xy) <$2 cm

The BESIII Collaboration

By Prof. W. Gradl



12 countries
58 institutions
$\sim$ 450 members

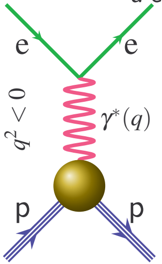
The Proton Electromagnetic Form Factors

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

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

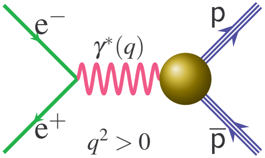
- The differential cross section for one photon exchange,

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



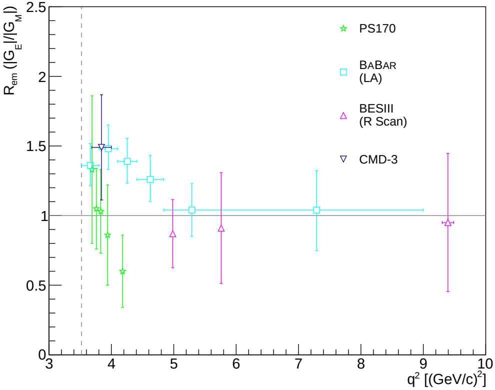
Space-Like
FFs Real

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



$M_{p\bar{p}}$, 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 extraction of the ratio $\frac{|G_E|}{|G_M|}$,

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

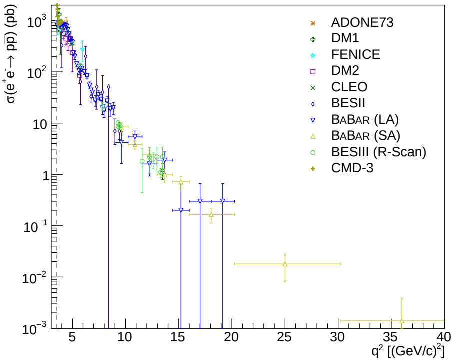
$\Rightarrow$ Maximum at 2 GeV/c^2,

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

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

PRD 87, 092005 (2013)
Nucl. Phys. B 411, 3 (1994)
PRD 91, 112004 (2015)

Data on Proton Time-Like Form Factor Ratio



Cross section

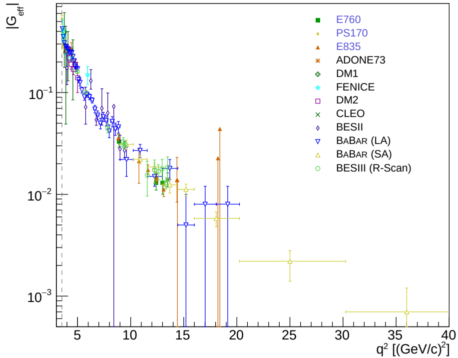
$e^+e^- \to p\overline{p}$

$$\sigma = \frac{4\pi\alpha^2\beta C}{3q^2}\left(|G_M|^2 + \frac{1}{2\tau}|G_E|^2\right)$$

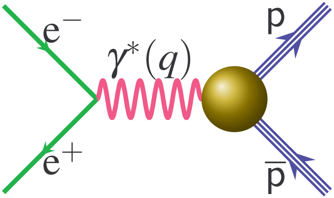
Effective FFs of proton

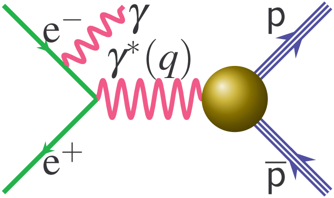
$e^+e^- \leftrightarrow p\overline{p}$

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



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	$\frac{d\sigma_{p\bar{p}}}{d(\cos\theta)} = \frac{\pi\alpha^2\beta C}{2q^2}[\lvert G_M\rvert^2(1+\cos^2\theta) + \frac{4m_p^2}{q^2}\lvert G_E\rvert^2\sin^2\theta]$	$\frac{d^2\sigma_{p\bar{p}\gamma}}{dq^2 d\theta_\gamma} = \frac{1}{s}W(s,x,\theta_\gamma)\sigma_{p\bar{p}}(q^2)$ $W(s,x,\theta_\gamma) = \frac{\alpha}{\pi x}(\frac{2-2x+x^2}{\sin^2\theta_\gamma} - \frac{x^2}{2})$
q^2	single at each beam energy	from threshold to s

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

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

The Status of BESIII Data

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

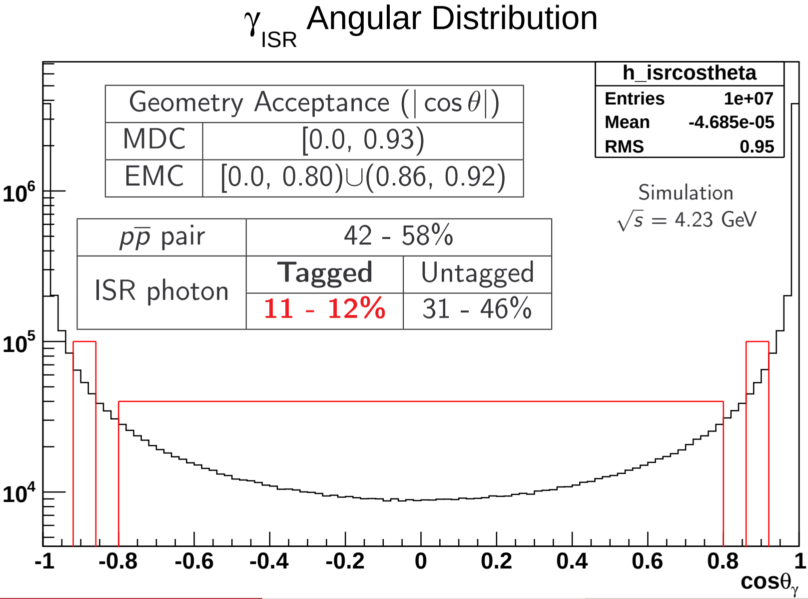
Data Sample	$\mathcal{L}_{int}$	Energy Range (GeV)	Notes
J/Ψ	$\sim$0.45 fb^{-1}	3.097	Large background contamination from resonance. Difficult to analyze
Ψ'	$\sim$0.8 fb^{-1}	3.686	
Ψ''	2.9 fb^{-1}	3.773	p FFs (tagged+untagged) and n FFs (tagged) with ISR, HIM
$\Psi(4040)$	0.5 fb^{-1}	4.009	
Y(4260)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

Total luminosity above Ψ'': 7.408 fb^{-1}.

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** 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,
  - $p\bar{p}\pi^0$ event veto.
- Backgrounds Studies:
  - **Inclusive** ($q\bar{q}$) MC events,
  - **Exclusive** background: $p\bar{p}\pi^0$ events.

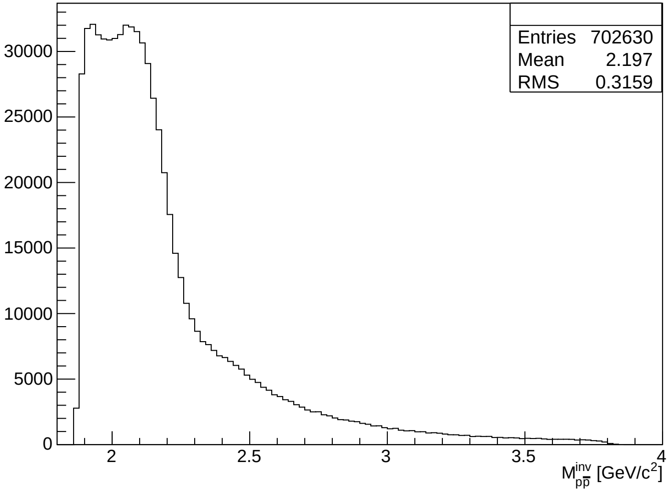
ISR Photon Angular Distribution from MC Simulation



Geometry Acceptance ($\lvert\cos\theta\rvert$)	
MDC	[0.0, 0.93)
EMC	$[0.0, 0.80) \cup (0.86, 0.92)$

$p\bar{p}$ pair	42 - 58%	
ISR photon	**Tagged**	Untagged
	11 - 12%	31 - 46%

$p\bar{p}$ Invariant Mass Spectrum from 4230 MC Simulation



$\sqrt{s} = 4.23$ GeV
10^7 generated

PHOKHARA 9.1
$e^+e^- \to p\bar{p}\gamma$

including
NLO, FSR and VP

Recontructed

Dominant Background Evaluation for ISR Ananlysis

- **Inclusive** ($q\bar{q}$) MC samples: $p\bar{p}\gamma_{ISR}$ and $p\bar{p}\pi^0$ survived.
- **Exclusive** (dominant) background $e^+e^-\rightarrow p\bar{p}\pi^0$
  - MC samples: 1×10^7 events generated (PHSP, BesEvtgen with ConExc model) for each energy point,
  - Apply $p\bar{p}\gamma$ alogrithm on MC sample,
  - Select $p\bar{p}\pi^0$ from **data** and **MC sample**
- Final $p\bar{p}\pi^0$ background pollution calculation.

$$\mathrm{H_{bkg}} = \mathrm{H}_{\pi^0}^{\mathrm{dat}} \times \frac{\mathrm{H}_{\mathrm{isr}}^{\mathrm{MC}}}{\mathrm{H}_{\pi^0}^{\mathrm{MC}}}$$

- Dominant background subtraction

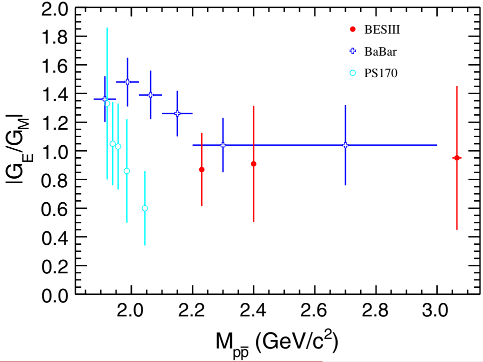
Extraction of the Proton FFs (Ratio) and the Cross Section

- Fit the angular distribution of the proton to extract the ratio of the proton FFs with 6 q^2-bins from the threshold of $p\bar{p}$ to 3.0 GeV,
- Calculate the cross sections and the effective FF of the proton with 31 q^2-bins at the same invariant mass range,
- Perform the systematic uncertainties study for both of the ratio and the cross sections.
- The results are comparable with the previous experiments.

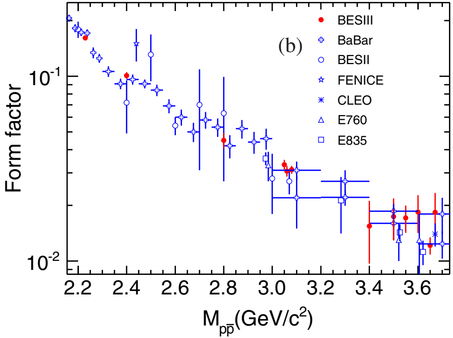
The First Results of Proton FFs from R-Scan at BESIII

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

Ratio of Proton FFs



The Proton Effective FF

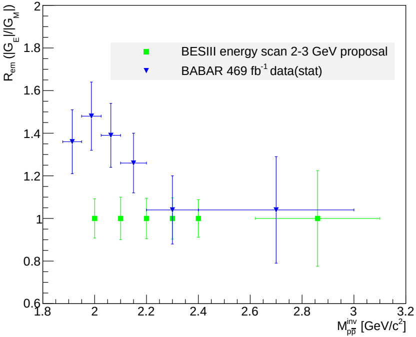


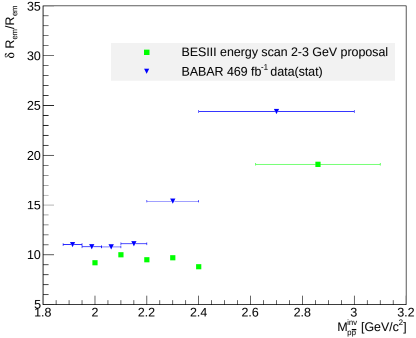
Energy Scan from 2.0 - 3.08 GeV at BESIII (Proposal)

Time-Like (from proposal)					Space-Like	
$M_{p\bar{p}}$	$\mathcal{L}$ (pb^{-1})	$\frac{\delta G_E}{G_E}$	$\frac{\delta G_M}{G_M}$	$\frac{\delta R_{em}}{R_{em}}$	$\sqrt{-q^2}$	$\frac{\delta R_{em}}{R_{em}}$
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.

Expected Accuracy of the Ratio ($\frac{|G_E|}{|G_M|}$) from Energy Scan





* The last point in the plots is a combination of the energy points 2.644, 2.9 and 3.1 GeV.

The Status of Energy Scan

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

Green points are MC Simulation for energy scan proposal study.

Conclusions and Outlook

- Two methods to measure proton EM FFs at BESIII.
- ISR analyses (tagged and untagged) above 3.773 GeV are in review, 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 q^2-bins**.
- An accuracy between 9% - 15% can be achieved for the ratio (R_{em}) with Energy Scan data.

Thank You for Your Attention!

Backup