Measurement of Proton Electromagnetic Form Factors in $e^+e^- \to p\bar{p}$ in energy region 2.0 - 3.08 GeV

Ch. Rosner[1,2], C. Morales[1], Y. D. Wang[1], F. E. Maas[1,2,3]
[1] Helmholtz-Institute Mainz
[2] Institute for Nuclear Physics, Johannes Gutenberg-University Mainz
[3] PRISMA Cluster of Excellence

L. Xia[4,a], X. R. Zhou[4,a], G. S. Huang[4,a], Z. G. Zhao[4,a]
[4] University of Science and Technology of China
[a] State Key Laboratory of Particle Detection and Electronics

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Outline

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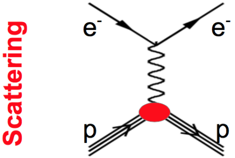
Introduction: Motivation I

- Account for the non point-like structure of hadrons.
- Proton form factors are fundamental hadron structure observables:
  - At low q^2: charge distribution and magnetization.
  - At higher q^2: dynamics, quark distribution.

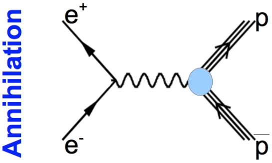
    Vector current, two form factors (2S+1):

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



Elastic scattering

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

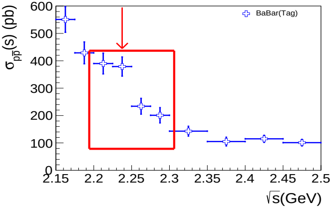


Annihilation into pair of proton/antiproton

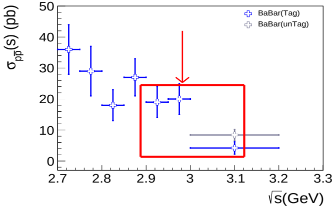
- Improve the uncertainty of cross section and electromagnetic form factor ratio. Study the $|G_E/G_M|$ for the proton.

Introduction: Motivation II

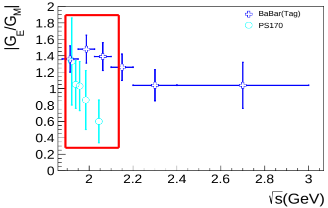
- Reveal the structure around 2.25 GeV and 3.0 GeV observed by BaBar PRD **87**, 092005 (2013) and PRD **88**, 072009 (2013).



(*a*) Cross section around 2.25 GeV



(*b*) Cross section around 3.0 GeV



(*c*) Disagreement between BaBar and PS170.

- Clarify whether the $|G_E/G_M|$ consistent with BaBar PRD **87**, 092005 (2013) or PS170 Nucl. Phys. **B411** (1994) 3.

Data sets and event selection $e^+e^- \to p\bar{p}$

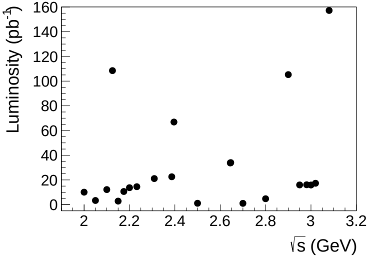
Data sets

- Boss version: BOSS6.6.5.p01 and BOSS6.6.4.p01.
- Data sets
  - 2015 R-scan data (Luminosity from Zhen Gao, BESIII 2015 Coll. summer Meeting)
  - 2012 R-scan data (Luminosity from Zhen Gao, Chin. Phys. C. **Vol. 40**, No. 6 (2017) 063001.)
  - 2015 Y(2175) data (Luminosity from Jingqing Zhang arXiv:1705.09722)
- The integrated luminosity of the analysed data sets is quoted here.

$\sqrt{s}$[GeV]	Run No.	Lumi[pb^{-1}]	$\sqrt{s}$[GeV]	Run No.	Lumi[pb^{-1}]
2	41729-41909	10.074	2.6444	40128-40296	34.003
2.05	41911-41958	3.343	2.6464	40300-40435	33.722
2.1	41588-41727	12.167	2.7	40436-40439	1.034
2.12655	42004-43253	108.490	2.8	28553-28575,	3.753
2.15	41533-41570	2.841		40440-40443	1.008
2.175	41416-41532	10.625	2.9	39775-40069	105.253
2.2	40989-41121	13.699	2.95	39619-39650	15.942
2.2324	28624-28648,	2.645	2.981	39651-39679	16.071
	41122-41239	11.856	3	39680-39710	15.881
2.3094	41240-41411	21.089	3.02	39711-39738	17.290
2.3864	40806-40951	22.549	3.08	27147-27233, 28241-28266,	31.019
2.396	40459-40769	66.869		39355-39618	126.185
2.5	40771-40776	1.098	-	-	-

Data sets

- The integrated luminosity of the analysed data sets is quoted in the figure below extracted from the reference on Page. 7.



Process	Size	Generator
$p\bar{p}$	2.5M	ConExc and PHOKHARA
$p\bar{p}\pi^+\pi^-$	1.5M	ConExc
$q\bar{q}$	3.5∼11M	ConExc
e^+e^-	2∼193M	Babayaga
$\mu^+\mu^-$	0.8∼89.6M	Babayaga
$\gamma\gamma$	1∼4.3M	Babayaga
$p\bar{p}\pi^0$	0.65M	ConExc
K^+K^-	0.5M	ConExc
$p\bar{p}\pi^0\pi^0$	0.5M	ConExc
$\pi^+\pi^-$	0.5M	PHOKHARA

- Main background (radiative Bhabha): at least as much as expected.
- $q\bar{q}$: at least 3 times as much as expected.
- K^+K^- MC is from Dong's work BAM-00250.

Event selection

- Good charged tracks

$$|V_r| < 1.0 \text{ cm}, \ |V_z| < 10 \text{ cm and } |cos\theta| < 0.93$$

- Charged tracks in a good event

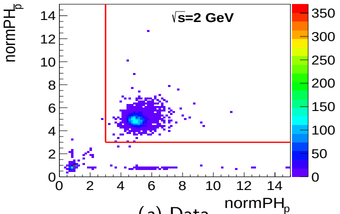
$$N_{Good} = 2 \text{ and } N_{Charge} = 0$$

- Particle identification
  - At (2.0, 2.05, 2.1, 2.125, 2.15) GeV, use dE/dx, normalized pulse height:

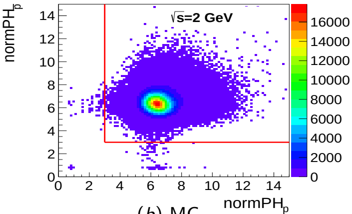
$$normPH > (3.0, 2.5, 2.0, 1.8, 1.7).$$

  - At (2.175∼3.08) GeV, use dE/dx and TOF

$$Prob(p) > Prob(e, \pi, K)$$



(a) Data



(b) MC

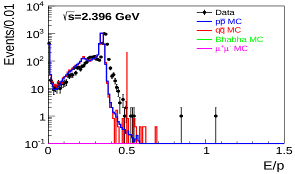
Normalized pulse height distribution of p and $\bar{p}$.

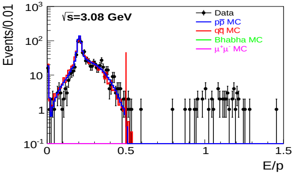
Event selection

- To veto Bhabha, for proton track, require:

$$E/p < 0.5$$

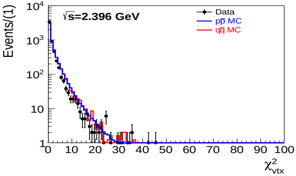
If there is no valid EMC information, the event is kept for further selection, but discarded at 3.08 GeV.

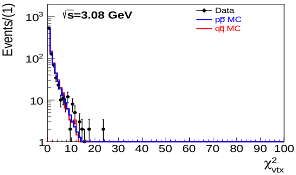




- Vertex fit to improve momentum resolution:

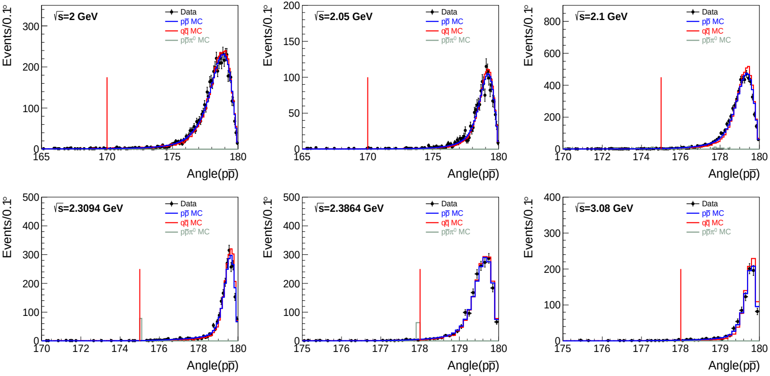
$$\chi^2_{vtx} < 100$$





Event selection

- To veto multi-tracks, require angle between p and $\bar{p}$ in center-of-mass:
  - $Angle_{cm}(p\bar{p}) > 170^{\circ}$, at 2.0, 2.05 GeV;
  - $Angle_{cm}(p\bar{p}) > 175^{\circ}$, at 2.1∼2.3094 GeV;
  - $Angle_{cm}(p\bar{p}) > 178^{\circ}$, at 2.3864∼3.08 GeV;



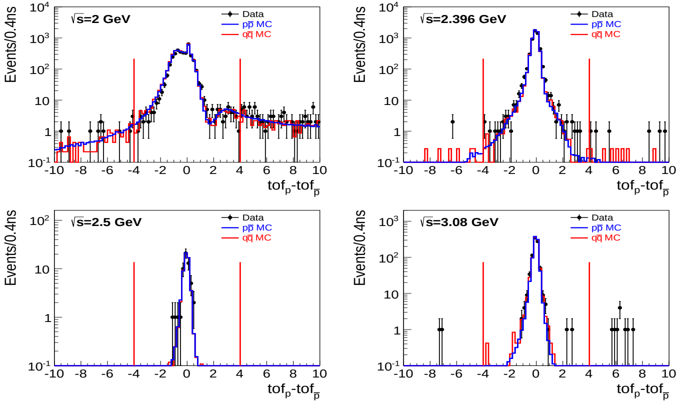
Angle between charged tracks at the e^+e^- center-of-mass.

Event selection

- To veto cosmic ray, require:

$$\Delta T = |TOF_p - TOF_{\bar{p}}| < 4 \text{ ns}$$

If no TOF information, the event is kept at (2.0∼2.396) GeV, but discarded at (2.5∼3.08) GeV



Time of flight difference between the charged tracks for different center-of-mass energies.

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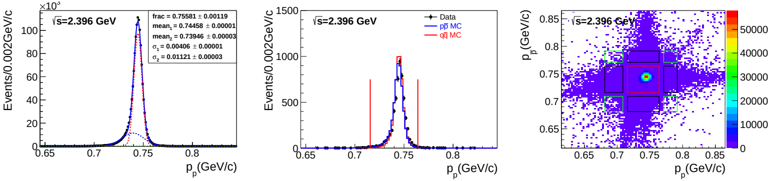
Event selection

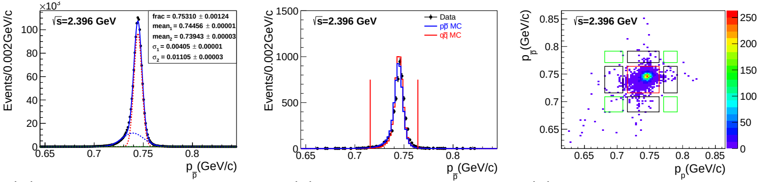
- Momentum window cut for p and $\bar{p}$:
  Signal region:

$$p_{mean} - 4\sigma < p_{cm}(p, \bar{p}) < p_{mean} + 3\sigma$$

p_{mean} and σ are from double gaussian fit to momentum of MC.



(a) MC Momentum fit of p. (b) Momentum cut of p. (c) MC Momentum window.



(d) MC Momentum fit of $\bar{p}$. (e) Momentum cut of $\bar{p}$. (f) Data Momentum window.

Background analysis

- No background event survives from the generated channels $e^+e^- \to e^+e^-$, $\mu^+\mu^-$ and $q\bar{q}$ etc.
- This upper limits for the contamination (95% confidence level) in the table below.

$\sqrt{s}$[GeV]	e^+e^-	$\mu^+\mu^-$	$q\bar{q}$	$\sqrt{s}$[GeV]	e^+e^-	$\mu^+\mu^-$	$q\bar{q}$
2	4.63	0.85	0.26	2.5	0.55	0.06	0.02
2.05	8.78	0.27	0.14	2.6444	5.09	0.82	0.40
2.1	30.48	0.93	0.50	2.6464	0.56	0.82	0.40
2.12655	52.99	1.29	1.96	2.7	0.45	0.05	0.03
2.15	6.79	0.21	0.11	2.8	1.12	0.02	0.11
2.175	24.82	0.76	0.48	2.9	2.68	1.16	1.99
2.2	31.28	0.96	0.60	2.95	0.40	0.28	0.48
2.2324	9.19	0.44	0.50	2.981	0.39	0.27	0.49
2.3094	7.32	1.34	0.81	3	0.38	0.26	0.48
2.3864	3.24	1.34	0.59	3.02	0.41	0.28	0.53
2.396	1.33	2.30	1.32	3.08	3.22	0.47	2.54

- The total background summing up e^+e^-, $\mu^+\mu^-$ and $q\bar{q}$, is less than 1% and we neglect it for the further analysis.

Cross section of $e^+e^- \to p\bar{p}$ and effective form factor

Detection efficiency: Model dependence

- Detection efficiency: Model (G_E/G_M) dependence.

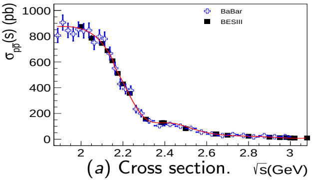
$$\frac{d\sigma_{p\bar{p}}(s)}{d\Omega} = \frac{\alpha^2\beta C}{4s}[|G_M(s)|^2(1+cos^2\theta_p) + \frac{4m_p^2}{s}|G_E(s)|^2 sin^2\theta_p]$$

- Model input: fit $\sigma_{p\bar{p}}$ and $|G_E/G_M|$ in the second to last round of iteration and BaBar result.

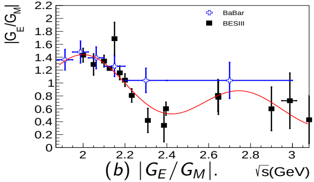
$$\sigma_{p\bar{p}}(s) = \begin{cases} \dfrac{a_0\pi^2\alpha^3}{s(1-e^{-\frac{-\pi\alpha_s(s)}{\beta(s)}})(1+(\frac{\sqrt{s}-2m_p}{a_1})^{a_2})} + a_3, \sqrt{s} \leq 2.15GeV \\ \displaystyle\sum_{i=4}^{10} a_i(\sqrt{s})^{i-4} + \frac{a_{11}}{\sqrt{2\pi}a_{12}} e^{-\frac{(\sqrt{s}-a_{13})^2}{2a_{12}^2}}, \sqrt{s} > 2.15GeV \end{cases}$$

$$|(G_E/G_M)(s)| = \frac{1}{b_8} e^{b_0+b_1\sqrt{s}}(b_2 + b_3\cos(b_4 + b_5\sqrt{s}))(1+\frac{s}{b_6})(1+\frac{s}{b_7})^2$$

- After several iterations, we input:



(a) Cross section.



(b) $|G_E/G_M|$.

Measurement of cross section and effective form factor

- Cross section measurement

$$\sigma_{p\bar{p}}(s) = \frac{N_{obs}}{\mathcal{L} \cdot \epsilon \cdot (1+\delta)}$$

  - N_{obs}: The observed number of signal in data.
  - $\mathcal{L}$: The integrated luminosity.
  - ϵ: Detection efficiency by MC sample generated by ConExc or PHOKHARA.
  - $1+\delta$: Radiative correction factor by ConExc or PHOKHARA.

- The total cross section:

$$\sigma_{p\bar{p}}(s) = \frac{4\pi\alpha^2\beta(s)C(s)}{3s}[|G_M(s)|^2 + \frac{2m_p^2}{s}|G_E(s)|^2]$$

Assume $|G(s)| = |G_E(s)| = |G_M(s)|$, the effective form factor is

$$|G(s)| = \sqrt{\frac{\sigma_{p\bar{p}}(s)}{\frac{4\pi\alpha^2\beta(s)C(s)}{3s}(1+\frac{2m_p^2}{s})}}$$

  - $\beta(s) = \sqrt{1-4m_p^2/s}$.
  - $C(s)$: Coulomb factor, $C(s) = \pi\alpha/\beta(s)/(1-\exp(-\pi\alpha/\beta(s)))$.

Result of cross section and effective form factor

- $\sigma_{dressed}$ is dressed cross section and $|G|$ is the effective form factor, generator is ConExc (BesEvtGen-00-03-69).

$\sqrt{s}$[GeV]	N_{obs}	$\mathcal{L}[pb^{-1}]$	ϵ[%]	$(1+\delta)$	$\epsilon(1+\delta)$[%]	$\sigma_{dressed}$[pb]	$\|G\|[10^{-2}]$
2	5287	10.074	66.53 ± 0.05	0.9014	59.97 ± 0.05	875.1 ± 12.1	27.98 ± 0.19
2.05	1693	3.343	70.13 ± 0.05	0.9215	64.62 ± 0.05	783.7 ± 19.1	25.40 ± 0.31
2.1	5985	12.167	70.23 ± 0.05	0.9428	66.21 ± 0.05	742.9 ± 9.6	24.20 ± 0.16
2.12655	50121	108.490	70.32 ± 0.05	0.9591	67.44 ± 0.05	685.1 ± 3.1	23.08 ± 0.05
2.15	1188	2.841	69.70 ± 0.05	0.9803	68.32 ± 0.05	612.1 ± 17.8	21.73 ± 0.32
2.175	3765	10.625	68.56 ± 0.05	1.0145	69.55 ± 0.05	509.5 ± 8.3	19.78 ± 0.16
2.2	4088	13.699	66.92 ± 0.05	1.0436	69.84 ± 0.05	427.3 ± 6.7	18.09 ± 0.14
2.2324	3640	14.501	64.55 ± 0.05	1.0991	70.94 ± 0.06	353.8 ± 5.9	16.47 ± 0.14
2.3094	2328	21.089	55.28 ± 0.05	1.2969	71.70 ± 0.06	154.0 ± 3.2	10.94 ± 0.11
2.3864	1850	22.549	50.70 ± 0.05	1.2859	65.19 ± 0.06	125.9 ± 2.9	10.01 ± 0.12
2.396	5507	66.869	51.36 ± 0.05	1.2747	65.48 ± 0.06	125.8 ± 1.7	10.02 ± 0.07
2.5	55	1.098	47.63 ± 0.04	1.3262	63.17 ± 0.06	79.3 ± 10.7	8.14 ± 0.55
2.6444	867	33.722	35.59 ± 0.04	1.7778	63.28 ± 0.07	40.6 ± 1.4	6.04 ± 0.10
2.6464	838	34.003	35.38 ± 0.04	1.7828	63.09 ± 0.07	39.1 ± 1.4	5.93 ± 0.10
2.7	20	1.034	33.89 ± 0.04	1.8470	62.59 ± 0.07	30.9 ± 6.9	5.35 ± 0.60
2.8	68	4.761	36.07 ± 0.04	1.7050	61.51 ± 0.06	23.2 ± 2.8	4.77 ± 0.29
2.9	1010	105.253	37.00 ± 0.04	1.6638	61.56 ± 0.06	15.6 ± 0.5	4.02 ± 0.06
2.95	118	15.942	34.68 ± 0.04	1.7853	61.91 ± 0.07	12.0 ± 1.1	3.57 ± 0.16
2.981	131	16.071	32.21 ± 0.04	1.9469	62.71 ± 0.07	13.0 ± 1.1	3.75 ± 0.16
3	93	15.881	30.05 ± 0.03	2.0941	62.93 ± 0.07	9.3 ± 1.0	3.19 ± 0.17
3.02	97	17.290	27.55 ± 0.03	2.2971	63.30 ± 0.08	8.9 ± 0.9	3.13 ± 0.16
3.08	860	157.204	21.83 ± 0.03	2.7747	60.58 ± 0.08	9.0 ± 0.3	3.22 ± 0.05
2.2324	676	2.645	64.70 ± 0.05	1.0991	71.11 ± 0.06	359.4 ± 13.8	16.60 ± 0.32
2.4	296	3.415	52.15 ± 0.05	1.2706	66.26 ± 0.06	130.8 ± 7.6	10.23 ± 0.30
2.8	53	3.753	36.07 ± 0.04	1.7050	61.49 ± 0.06	23.0 ± 3.2	4.74 ± 0.33
3.05	88	14.893	23.78 ± 0.03	2.6653	63.37 ± 0.08	9.3 ± 1.0	3.24 ± 0.17
3.06	77	15.040	22.77 ± 0.03	2.7797	63.29 ± 0.08	8.1 ± 0.9	3.03 ± 0.17
3.08	164	31.019	21.93 ± 0.03	2.7747	60.85 ± 0.08	8.7 ± 0.7	3.15 ± 0.12

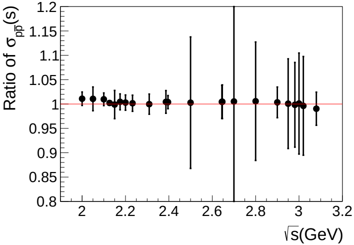
Result of cross section and effective form factor

- $\sigma_{dressed}$ is dressed cross section and $|G|$ is the effective form factor, generator is PHOKHARA v9.1.

$\sqrt{s}$[GeV]	N_{obs}	$\mathcal{L}[pb^{-1}]$	$\epsilon[\%]$	$(1+\delta)$	$\epsilon(1+\delta)[\%]$	$\sigma_{dressed}$[pb]	$\|G\|[10^{-2}]$
2	5297	10.074	67.28 ± 0.05	0.903	60.78 ± 0.05	865.1 ± 11.9	27.82 ± 0.19
2.05	1695	3.343	70.60 ± 0.05	0.926	65.35 ± 0.05	775.9 ± 18.9	25.27 ± 0.31
2.1	5989	12.167	70.38 ± 0.05	0.949	66.81 ± 0.05	736.7 ± 9.5	24.10 ± 0.16
2.12655	50161	108.490	70.34 ± 0.05	0.960	67.51 ± 0.05	684.8 ± 3.1	23.08 ± 0.05
2.15	1189	2.841	69.68 ± 0.05	0.984	68.54 ± 0.05	610.6 ± 17.7	21.70 ± 0.31
2.175	3764	10.625	68.52 ± 0.05	1.016	69.62 ± 0.05	508.9 ± 8.3	19.76 ± 0.16
2.2	4089	13.699	66.82 ± 0.05	1.044	69.76 ± 0.05	427.9 ± 6.7	18.10 ± 0.14
2.2324	3643	14.501	64.32 ± 0.05	1.099	70.70 ± 0.06	355.3 ± 5.9	16.50 ± 0.14
2.3094	2330	21.089	54.59 ± 0.05	1.299	70.89 ± 0.06	155.9 ± 3.2	11.00 ± 0.11
2.3864	1852	22.549	50.69 ± 0.05	1.267	64.24 ± 0.06	127.9 ± 3.0	10.09 ± 0.12
2.396	5511	66.869	51.43 ± 0.05	1.254	64.47 ± 0.06	127.8 ± 1.7	10.10 ± 0.07
2.5	55	1.098	47.96 ± 0.04	1.280	61.37 ± 0.06	81.6 ± 11.0	8.26 ± 0.56
2.6444	868	33.722	37.54 ± 0.04	1.670	62.68 ± 0.06	41.1 ± 1.4	6.07 ± 0.10
2.6464	840	34.003	37.27 ± 0.04	1.675	62.45 ± 0.06	39.6 ± 1.4	5.96 ± 0.10
2.7	20	1.034	34.93 ± 0.04	1.795	62.71 ± 0.07	30.8 ± 6.9	5.34 ± 0.60
2.8	68	4.761	33.45 ± 0.04	1.858	62.17 ± 0.07	23.0 ± 2.8	4.74 ± 0.29
2.9	1012	105.253	30.72 ± 0.04	2.022	62.13 ± 0.07	15.5 ± 0.5	4.00 ± 0.06
2.95	118	15.942	26.64 ± 0.03	2.330	62.07 ± 0.08	11.9 ± 1.1	3.56 ± 0.16
2.981	132	16.071	23.45 ± 0.03	2.664	62.46 ± 0.08	13.1 ± 1.1	3.77 ± 0.16
3	93	15.881	21.44 ± 0.03	2.910	62.38 ± 0.09	9.4 ± 1.0	3.21 ± 0.17
3.02	97	17.290	19.81 ± 0.03	3.125	61.93 ± 0.09	9.1 ± 0.9	3.17 ± 0.16
3.08	856	157.204	24.15 ± 0.03	2.366	57.14 ± 0.07	9.5 ± 0.3	3.30 ± 0.06

Comparison between ConExc and PHOKHARA

- The difference of cross section between ConExc and PHOKHARA as the figure right and the table below.
- There is also 1% difference in detection efficiency between ConExc versions BesEvtGen-00-03-69 and BesEvtGen-00-03-18, this problem have reported to Ronggang Ping.

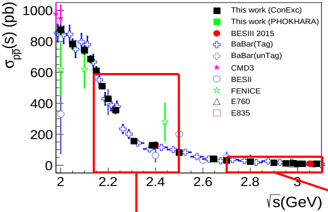


Ratio of cross section from ConExc and PHOKHARA.

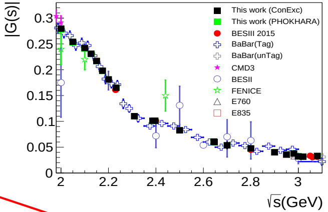
$\sqrt{s}$[GeV]	$\sigma^{ConExc}_{dressed}$[pb]	$\sigma^{PHOKHARA}_{dressed}$[pb]	Δ[%]	$\sqrt{s}$[GeV]	$\sigma^{ConExc}_{dressed}$[pb]	$\sigma^{PHOKHARA}_{dressed}$[pb]	Δ[%]
2	874.6 ± 12.0	865.1 ± 11.9	1.08	2.5	81.8 ± 11.0	81.6 ± 11.0	0.27
2.05	784.1 ± 19.1	775.9 ± 18.9	1.05	2.6444	41.2 ± 1.4	41.1 ± 1.4	0.44
2.1	743.9 ± 9.6	736.7 ± 9.5	0.96	2.6464	39.7 ± 1.4	39.6 ± 1.4	0.47
2.12655	686.3 ± 3.1	684.8 ± 3.1	0.22	2.7	31.0 ± 6.9	30.8 ± 6.9	0.52
2.15	609.9 ± 17.7	610.6 ± 17.7	0.11	2.8	23.1 ± 2.8	23.0 ± 2.8	0.57
2.175	511.1 ± 8.3	508.9 ± 8.3	0.44	2.9	15.5 ± 0.5	15.5 ± 0.5	0.34
2.2	429.1 ± 6.7	427.9 ± 6.7	0.29	2.95	11.9 ± 1.1	11.9 ± 1.1	0.07
2.2324	355.9 ± 5.9	355.3 ± 5.9	0.16	2.981	13.1 ± 1.1	13.1 ± 1.1	0.16
2.3094	155.8 ± 3.2	155.9 ± 3.2	0.03	3	9.4 ± 1.0	9.4 ± 1.0	0.10
2.3864	128.4 ± 3.0	127.9 ± 3.0	0.43	3.02	9.0 ± 0.9	9.1 ± 0.9	0.38
2.396	128.3 ± 1.7	127.8 ± 1.7	0.38	3.08	9.4 ± 0.3	9.5 ± 0.3	0.97

Result comparison of cross section and effective form factor

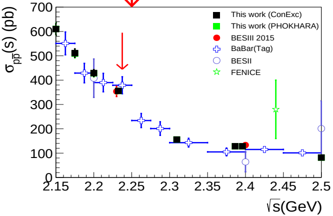
- Results comparison of dressed cross section and effective form factor.



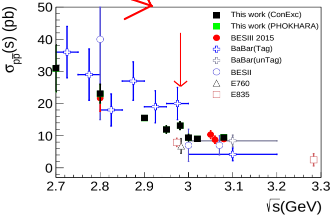
(a) Result of cross section.



(b) Effective form factor.



(c) Cross section around 2.25 GeV.



(d) Cross section around 3 GeV.

Extraction of electromagnetic form factor ratio

Electromagnetic form factor

- Fit on the polar angular distribution of proton.
  There are two parameters, $|G_E/G_M|$ and $|G_M|$ ($|G_M|$ is contained in global normalization) to fit. The fitting formula for the proton angular distribution is expressed as:

$$\frac{d\mathrm{N}}{\epsilon(1+\delta)\times d\cos\theta_p} = \frac{\mathcal{L}\hbar c\pi\alpha^2\beta(s)C(s)}{2s}|G_M(s)|^2[(1+\cos^2\theta_p) + \frac{4m_p^2}{s}|\frac{G_E}{G_M}|(s)^2(1-\cos^2\theta_p)]$$

  - $\epsilon(1+\delta)(\cos\theta_p)$: ISR-efficiency correction, calculated by dividing the $\cos\theta_p$ distribution after reconstruction by that from the MCTruth of Born sample, with the same luminosity.

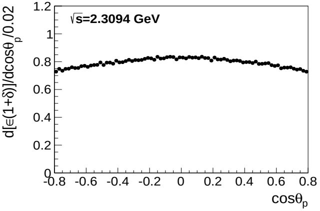
- $|G_M|$ can be extracted from formula below:

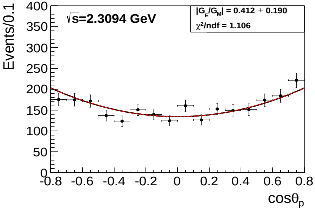
$$|G_M(s)| = \sqrt{\frac{\sigma_{p\bar{p}}(s)}{\frac{4\pi\alpha^2\beta(s)C(s)}{3s}(1+\frac{2m_p^2}{s}|\frac{G_E}{G_M}|(s)^2)}}$$

$|G_E(s)|$ and $|G_M(s)|$ can be calculated from $\sigma_{p\bar{p}}(s)$ and $|G_E/G_M|(s)$.

ISR-Efficiency correction

- Left: $\epsilon(1+\delta)$ curves in the last round of iteration.
- Right: fit on $\cos\theta_p$ distribution from data corrected by $\epsilon(1+\delta)$ curves.





$\sqrt{s}$[GeV]	$\lvert G_E/G_M\rvert$	χ^2	$\sqrt{s}$[GeV]	$\lvert G_E/G_M\rvert$	χ^2
2	1.47 ± 0.11	0.57	2.3094	0.41 ± 0.19	1.18
2.05	1.31 ± 0.17	0.55	2.3864	0.34 ± 0.26	0.82
2.1	1.31 ± 0.09	1.43	2.396	0.60 ± 0.10	1.06
2.12655	1.23 ± 0.03	3.54	2.6444	0.83 ± 0.25	0.71
2.15	1.64 ± 0.24	0.84	2.6464	0.76 ± 0.33	0.87
2.175	1.18 ± 0.11	1.53	2.9	0.66 ± 0.33	1.25
2.2	1.05 ± 0.10	1.22	2.988	0.68 ± 0.45	0.78
2.2324	0.80 ± 0.10	0.88	3.08	0.46 ± 0.36	0.59

Method of moments

- Alternative method for the extraction of $|G_E/G_M|$: Method of moments.

$$<\cos^2\theta>=\frac{N_1}{N_{norm}}\int_{x_{min}}^{x_{max}}\cos^2\theta\left\{[(1+\cos^2\theta)]|G_M|^2+\frac{4m_p^2}{s}\sin^2\theta|G_E|^2\right\}d\cos\theta$$

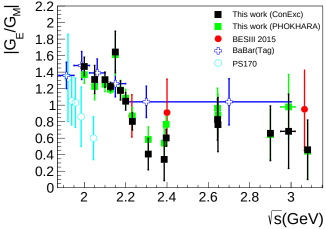
$$|\frac{G_E}{G_M}|=\sqrt{\frac{s}{4m_p^2}\frac{y_4-y_2<\cos^2\theta>}{<\cos^2\theta>y_1-y_3}}$$

$$\Delta|\frac{G_E}{G_M}|=\frac{s}{4m_p^2}(1/|\frac{G_E}{G_M}|)\frac{y_1y_4-y_2y_3}{2(y_3-y_1<\cos^2\theta>)^2}\Delta<\cos^2\theta>$$

- $N_1=\frac{L(1+\delta)\hbar c\pi\alpha^2\beta C}{2s}$,
- $y_1=\int_{x_{min}}^{x_{max}}(1-x^2)dx,\quad y_2=\int_{x_{min}}^{x_{max}}(1+x^2)dx,$
- $y_3=\int_{x_{min}}^{x_{max}}(x^2-x^4)dx,\quad y_4=\int_{x_{min}}^{x_{max}}(x^2+x^4)dx,$
- $\Delta<\cos^2\theta>=\sqrt{(\frac{1}{N_{norm}}\sum_{i=0}^{N_{norm}}\cos^2\theta)^2-\frac{1}{N_{norm}}\sum_{i=0}^{N_{norm}}\cos^4\theta}.$

Results of electromagnetic form factors

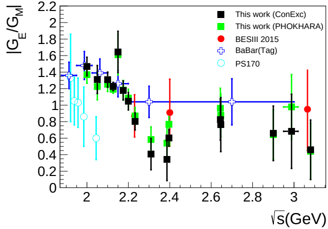
- The figure shows $|G_E/G_M|$ of proton, compared with
  BESIII 2015 PRD **91**, 112004 (2015),
  BaBar PRD **87**, 092005 (2013),
  PS170 Nucl. Phys. **B411** (1994) 3
  The table summarizes the results using the two different methods.



$\sqrt{s}$(GeV)	$\|G_E/G_M\|$			$\|G_M\|$ $[10^{-2}]$		
	Method of Fit	Method of Moments	Δ_{Rem}[%]	Method of Fit	Method of Moments	$\Delta_{\|G_M\|}$[%]
2	1.48 ± 0.11	1.48 ± 0.10	0.27	23.97 ± 0.87	23.94 ± 0.83	0.13
2.05	1.31 ± 0.16	1.28 ± 0.16	2.40	23.09 ± 1.25	23.32 ± 1.21	1.01
2.1	1.32 ± 0.09	1.33 ± 0.09	1.02	22.01 ± 0.62	21.92 ± 0.62	0.42
2.12655	1.23 ± 0.03	1.23 ± 0.03	0.33	21.57 ± 0.20	21.60 ± 0.20	0.12
2.15	1.69 ± 0.25	1.62 ± 0.24	4.10	17.69 ± 1.39	18.07 ± 1.35	2.16
2.175	1.19 ± 0.11	1.20 ± 0.11	0.84	18.74 ± 0.61	18.68 ± 0.60	0.29
2.2	1.07 ± 0.10	1.10 ± 0.10	2.73	17.73 ± 0.50	17.58 ± 0.50	0.81
2.2324	0.84 ± 0.10	0.86 ± 0.10	3.01	17.16 ± 0.44	17.06 ± 0.44	0.60
2.3094	0.51 ± 0.16	0.50 ± 0.16	2.44	12.10 ± 0.33	12.13 ± 0.33	0.19
2.3864	0.50 ± 0.20	0.49 ± 0.20	1.51	11.04 ± 0.33	11.05 ± 0.33	0.11
2.396	0.72 ± 0.09	0.75 ± 0.09	3.23	10.63 ± 0.20	10.59 ± 0.20	0.45
2.6444	0.92 ± 0.24	0.99 ± 0.24	8.28	6.14 ± 0.30	6.05 ± 0.31	1.48
2.6464	0.84 ± 0.26	0.83 ± 0.26	1.70	6.11 ± 0.30	6.12 ± 0.30	0.26
2.9	0.33 ± 0.48	0.34 ± 0.49	0.64	4.37 ± 0.16	4.37 ± 0.16	0.01
2.988	0.72 ± 0.43	0.83 ± 0.42	15.36	3.56 ± 0.22	3.51 ± 0.23	1.50
3.08	0.14 ± 1.38	$- \pm -$	–	3.50 ± 0.14	$- \pm -$	–
2.2324	0.72 ± 0.24	0.75 ± 0.24	3.79	17.74 ± 0.98	17.64 ± 0.99	0.59
2.4	0.88 ± 0.38	0.75 ± 0.40	14.80	10.51 ± 0.92	10.80 ± 0.91	2.72
3.068	0.57 ± 0.62	0.73 ± 0.55	29.60	3.33 ± 0.23	3.27 ± 0.24	1.87

Results of electromagnetic form factors

- The figure shows $|G_E/G_M|$ of proton, use Xiaorong's method compared with
  BESIII 2015 PRD **91**, 112004 (2015),
  BaBar PRD **87**, 092005 (2013),
  PS170 Nucl. Phys. **B411** (1994) 3
  The table summarizes the results using the two different methods.



$\sqrt{s}$(GeV)	$\lvert G_E/G_M \rvert$			$\lvert G_M \rvert$ $[10^{-2}]$		
	Our Method of fit	Xiaorong Method of fit	Δ_{Rem}[%]	Our Method of fit	Xiaorong Method of fit	$\Delta_{\lvert G_M \rvert}$[%]
2	1.48 ± 0.11	1.50 ± 0.11	1.54	23.97 ± 0.87	23.79 ± 0.88	0.75
2.05	1.31 ± 0.16	1.32 ± 0.17	0.89	23.09 ± 1.25	23.01 ± 1.31	0.37
2.1	1.32 ± 0.09	1.35 ± 0.10	2.40	22.01 ± 0.62	21.80 ± 0.68	0.98
2.12655	1.23 ± 0.03	1.25 ± 0.03	1.76	21.57 ± 0.20	21.43 ± 0.22	0.65
2.15	1.69 ± 0.25	1.67 ± 0.29	0.72	17.69 ± 1.39	17.76 ± 1.59	0.38
2.175	1.19 ± 0.11	1.22 ± 0.12	2.20	18.74 ± 0.61	18.59 ± 0.65	0.76
2.2	1.07 ± 0.10	1.11 ± 0.11	3.09	17.73 ± 0.50	17.56 ± 0.55	0.92
2.2324	0.84 ± 0.10	0.86 ± 0.11	3.42	17.16 ± 0.44	17.04 ± 0.49	0.68
2.3094	0.51 ± 0.16	0.55 ± 0.17	8.66	12.10 ± 0.33	12.02 ± 0.37	0.71
2.3864	0.50 ± 0.20	0.53 ± 0.20	6.68	11.04 ± 0.33	10.98 ± 0.35	0.49
2.396	0.72 ± 0.09	0.77 ± 0.10	5.85	10.63 ± 0.20	10.55 ± 0.22	0.82
2.6444	0.92 ± 0.24	1.00 ± 0.27	9.25	6.14 ± 0.30	6.04 ± 0.35	1.65
2.6464	0.84 ± 0.26	0.87 ± 0.28	3.20	6.11 ± 0.30	6.08 ± 0.33	0.49
2.9	0.33 ± 0.48	0.38 ± 0.47	14.95	4.37 ± 0.16	4.35 ± 0.17	0.36
2.988	0.72 ± 0.43	0.86 ± 0.47	19.17	3.56 ± 0.22	3.49 ± 0.25	1.90
3.08	0.14 ± 1.38	0.19 ± 2.75	37.61	3.50 ± 0.14	3.49 ± 0.34	0.16
2.2324	0.72 ± 0.24	0.75 ± 0.27	3.40	17.74 ± 0.98	17.65 ± 1.11	0.53
2.4	0.88 ± 0.38	0.89 ± 0.42	1.36	10.51 ± 0.92	10.49 ± 1.01	0.26
3.068	0.57 ± 0.62	0.83 ± 0.54	46.06	3.33 ± 0.23	3.23 ± 0.25	3.06

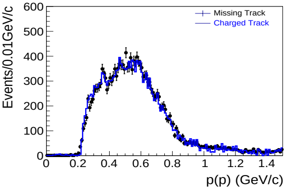
Systematic uncertainty

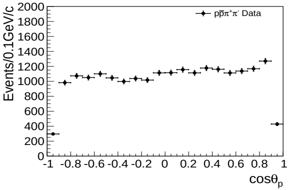
Control sample

- Control sample: $p\bar{p}\pi^+\pi^-$
- Boss version: BOSS6.6.5.p01
- Data sets
  - 2015 R-scan data (Zhen Gao, BESIII 2015 Coll. summer Meeting)

$\sqrt{s}$[GeV]	Run No.	Lumi[pb^{-1}]	$\sqrt{s}$[GeV]	Run No.	Lumi[pb^{-1}]
2.3864	40806-40951	22.549	2.95	39619-39650	15.942
2.396	40459-40769	66.869	2.981	39651-39679	16.071
2.6444	40128-40296	34.003	3	39680-39710	15.881
2.6464	40300-40435	33.722	3.02	39711-39738	17.290
2.9	39775-40069	105.253	3.08	39355-39618	126.185

- Comparison of charged track and missing track, and angular distribution of missing track.





Tracking efficiency studies

- Event selection:
  - Good charged tracks:

    $$|V_r| < 1.0 \text{ cm}, \ |V_z| < 10 \text{ cm and } |cos\theta| < 0.93$$

  - Particle identification:
    - ✓ Use dE/dx and TOF
    - ✓ $N_{\pi^+} = N_{\pi^-} = 1$; $Prob(\pi) > Prob(K, p)$
    - ✓ $N_p = 1$ or $N_{\bar{p}} = 1$; $Prob(p) > Prob(\pi, K)$
  - Vertex fit ($\bar{p}\pi^+\pi^-$ or $p\pi^+\pi^-$)
  - Recoil method:

    $$(p)_{E,p} = e.c.m_{E,p} - (\bar{p}\pi^+\pi^-)_{E,p}$$

    or

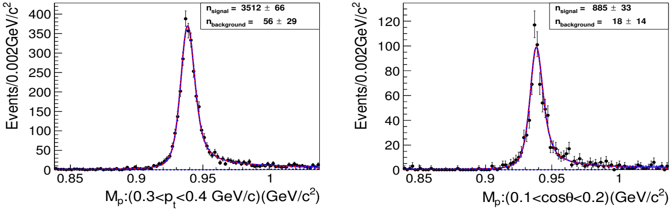
    $$(\bar{p})_{E,p} = e.c.m_{E,p} - (p\pi^+\pi^-)_{E,p}$$

  - Charged tracks in a good event:
    - ✓ $N_{Good} = 3$ or 4, Recoil of p or $\bar{p}$ (Number of p and $\bar{p}$: N_p, $N_{\bar{p}}$)
    - ✓ $N_{Good} = 4$, Recoil of p or $\bar{p}$ (Number of p and $\bar{p}$: n_p, $n_{\bar{p}}$)
  - Tracking efficiency:

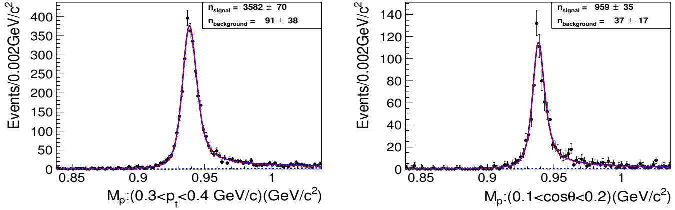
    $$\epsilon_{Track,p} = \frac{n_p}{N_p}, \ \epsilon_{Track,\bar{p}} = \frac{n_{\bar{p}}}{N_{\bar{p}}}$$

Tracking efficiency studies

- The number is obtained by fit, the fitting function is $MCshape \otimes Gaussian + polynomial$



$(a)\ N_{Good} = 4$



$(b)\ N_{Good} = 3$ or 4

Particle identification (NormPH) efficiency studies

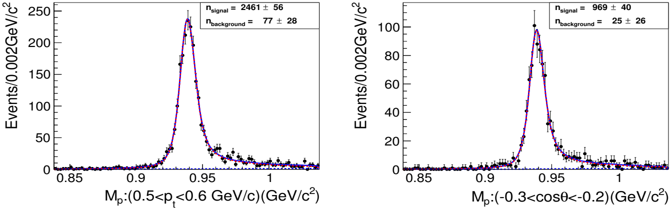
- Control sample: $p\bar{p}$ for 2.0∼2.15 GeV
- Event selection:
  - Good charged tracks:
    $$|V_r| < 1.0 \text{ cm}, |V_z| < 10 \text{ cm and } |cos\theta| < 0.8$$
  - Charged tracks in a good event
    $$N_{Good} = 2,\ N_{Charge} = 0$$
  - Vertex fit: $\chi^2_{vtx} < 100$
  - Require angle between p and $\bar{p}$ in center-of-mass:
    - ✓ $Angle_{cm}(p\bar{p}) > 175^\circ$, at 2.0 GeV;
    - ✓ $Angle_{cm}(p\bar{p}) > 176^\circ$, at 2.1 GeV, 2.125 GeV.
  - Require TOF difference between the charged tracks
    $$\Delta T = |TOF_p - TOF_{\bar{p}}| < 4 \text{ ns}$$
    If no TOF information, the event is kept.
  - Momentum window cut for p and $\bar{p}$:
    $$p_{mean} - 4\sigma < p_{cm}(p, \bar{p}) < p_{mean} + 3\sigma$$
  - PID in a good event:
    - ✓ $N_{por\bar{p}} = 0$ or 1, Recoil of p or $\bar{p}$ (Number of p and $\bar{p}$: N_p, $N_{\bar{p}}$)
    - ✓ $N_{por\bar{p}} = 1$, Recoil of p or $\bar{p}$ (Number of p and $\bar{p}$: n_p, $n_{\bar{p}}$)
  - PID efficiency:
    $$\epsilon_{PID,p} = \frac{n_p}{N_p},\ \epsilon_{PID,\bar{p}} = \frac{n_{\bar{p}}}{N_{\bar{p}}}$$

Particle identification efficiency studies

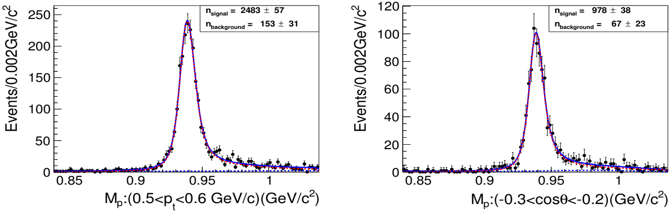
- Control sample: $p\bar{p}\pi^+\pi^-$ for 2.175∼3.08 GeV
- Event selection:
  - Good charged tracks:
    $$|V_r| < 1.0 \text{ cm}, |V_z| < 10 \text{ cm and } |cos\theta| < 0.93$$
  - Charged tracks in a good event
    $$N_{Good} = 4,\ N_{Charge} = 0$$
  - Particle identification:
    - ✓ Use dE/dx and TOF
    - ✓ $N_{\pi^+} = N_{\pi^-} = 1;\ Prob(\pi) > Prob(K, p)$
    - ✓ $N_p = 1$ or $N_{\bar{p}} = 1;\ Prob(p) > Prob(e, \pi, K)$
  - Vertex fit
  - Recoil method:
    $$(p)_{E,p} = e.c.m_{E,p} - (\bar{p}\pi^+\pi^-)_{E,p}$$
    or
    $$(\bar{p})_{E,p} = e.c.m_{E,p} - (p\pi^+\pi^-)_{E,p}$$
  - PID in a good event:
    - ✓ $N_{por\bar{p}} = 0$ or 1, Recoil of p or $\bar{p}$ (Number of p and $\bar{p}$: N_p, $N_{\bar{p}}$)
    - ✓ $N_{por\bar{p}} = 1$, Recoil of p or $\bar{p}$ (Number of p and $\bar{p}$: n_p, $n_{\bar{p}}$)
  - Tracking efficiency:
    $$\epsilon_{PID,p} = \frac{n_p}{N_p},\ \epsilon_{PID,\bar{p}} = \frac{n_{\bar{p}}}{N_{\bar{p}}}$$

Particle identification efficiency studies

- The number is obtained by fit, the fitting function is $MCshape \otimes Gaussian + polynomial$



$(a)\ N_p = 1$



$(b)\ N_p = 0$ or 1

Tracking/PID efficiency and uncertainty definition

- Tracking/PID efficiency:

$$\epsilon = \frac{n}{N}$$

- The uncertainty on the tracking/PID efficiency is:

$$\sigma_\epsilon = \sqrt{\left(-\frac{\epsilon}{N}\ \frac{1}{N}\right)\begin{pmatrix}(\sigma_N)^2 & (\sigma_n)^2 \\ (\sigma_n)^2 & (\sigma_n)^2\end{pmatrix}\begin{pmatrix}-\frac{\epsilon_{trk}}{N} \\ \frac{1}{N}\end{pmatrix}}$$
$$= \frac{1}{N}\sqrt{(1-2\epsilon)(\sigma_n)^2 + \epsilon_{trk}^2(\sigma_N)^2}$$

- Tracking/PID systematic uncertainty:

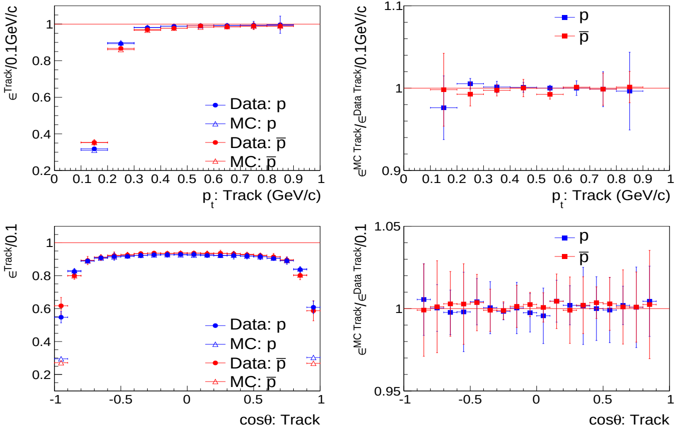
$$\Delta = 1 - \frac{\epsilon(MC)}{\epsilon(data)}$$

- The uncertainty of tracking/PID systematic uncertainty is:

$$\sigma_\Delta = (1-\Delta)\cdot\sqrt{\frac{\sigma^2_{\epsilon(MC)}}{\epsilon^2(MC)} + \frac{\sigma^2_{\epsilon(data)}}{\epsilon^2(data)}}$$

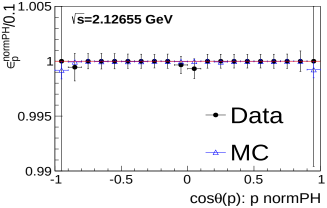
Tracking efficiency studies

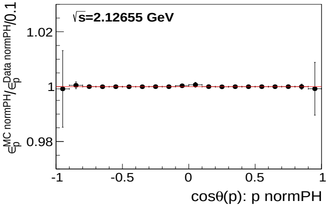
- Comparison of tracking efficiency for p (blue) and $\bar{p}$ (red) between data (dot) and MC (triangle).
- Take 1.0% as the tracking efficiency uncertainty for p and $\bar{p}$.

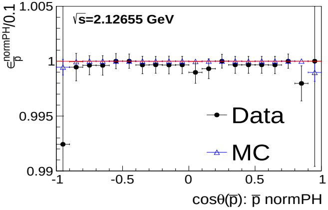


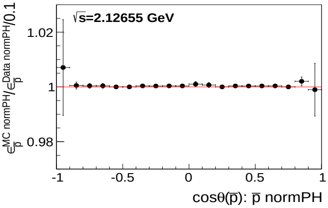
Particle identification (NormPH) efficiency studies

- Comparison of normPH efficiency for p and $\bar{p}$ between data (dot) and MC (triangle).
- Take 1.0% as the normPH efficiency uncertainty for p and $\bar{p}$.



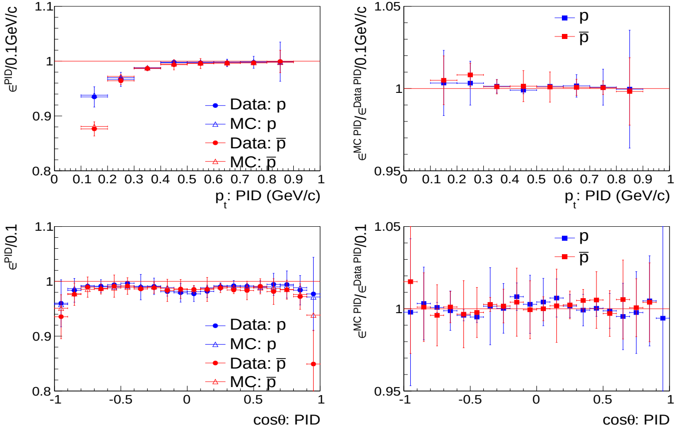






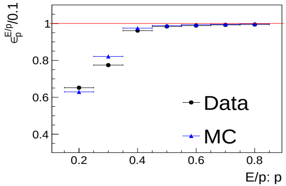
Particle identification efficiency studies

- Comparison of PID efficiency for p (blue) and $\bar{p}$ (red) between data (dot) and MC (triangle).
- Take 1.0% as the PID efficiency uncertainty for p and $\bar{p}$.



Other systematic uncertainty

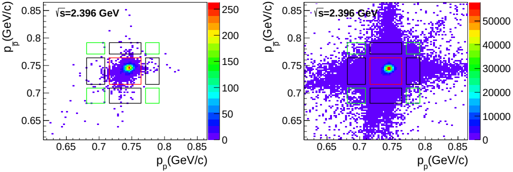
- From E/p ratio
  - We select a sample from the process $p\bar{p}\pi^+\pi^-$. It is safe to apply the cut $E/p < 0.5$. And it will bring in 0.2% uncertainty.



- From other selection criteria
  - We change the cut value to get the cross section and $|G_E/G_M|$ to get systematic uncertainty.
  - Time of flight difference between the charged tracks ΔT: 4ns change to 3ns and 5ns.
  - Angle between the tracks at the center-of-mass $Angle_{cm}(p\bar{p})$:
    - ✓ At 2.0, 2.05 GeV, 170° change to 168° and 172°;
    - ✓ At 2.1∼2.3094 GeV, 175° change to 174° and 176°;
    - ✓ At 2.3864∼3.08 GeV, 178° change to 177° and 179°.
  - Momentum window:
    - ✓ Change the lower limit from -4σ to -5σ and the upper limit from $+3\sigma$ to $+4\sigma$;
    - ✓ Change the lower limit from -4σ to -3.5σ and the upper limit from $+3\sigma$ to $+2.5\sigma$.

Other systematic uncertainty

- From luminosity measurement: see from Zhen Gao, BESIII 2015 Coll. summer Meeting and Chin. Phys. C. **Vol. 40**, No. 6 (2017) 063001.
- From background
  - We subtracted the background using the 2 dimensional sideband method propose for both data and MC, the systematic uncertainty is the difference of cross section and $|G_E/G_M|$. 0.5(n2+n4+n6+n8-0.5(n1+n3+n7+n9))



(*a*) Data Momentum window. (*b*) MC Momentum window.

- From tuning
  - Uncertainty from tuning is estimated as the difference between the nominal result and the results from the second MC tuning. Please see the Appendix. 16.

Systematic uncertainty in cross section measurement

- Summary of systematic uncertainties in cross section and effective form factor measurement as the table below:

$\sqrt{s}$ (GeV)	Δ_σ^{trk} [%]	Δ_σ^{PID} [%]	$\Delta_\sigma^{E/p}$ [%]	Δ_σ^{TOF} [%]	Δ_σ^{ang} [%]	Δ_σ^{p} [%]	Δ_σ^{bkg} [%]	Δ_σ^{lumi} [%]	Δ_σ^{model} [%]	Δ_σ^{tot} [%]	$\Delta_{\lvert G \rvert}^{tot}$ [%]
2	2	2	0.2	0.12	0.17	0.24	0.18	0.67	0.13	2.94	1.47
2.05	2	2	0.2	0.03	0.09	0.92	0.11	0.81	0.08	3.09	1.55
2.1	2	2	0.2	0.06	0.63	0.10	0.06	0.70	0.02	2.99	1.50
2.12655	2	2	0.2	0.05	0.71	0.13	0.09	0.89	0.09	3.06	1.53
2.15	2	2	0.2	0.12	1.18	0.21	0.35	0.85	0.11	3.22	1.61
2.175	2	2	0.2	0.12	0.82	0.26	0.38	0.86	0.03	3.11	1.56
2.2	2	2	0.2	0.05	0.56	0.20	0.01	0.67	0.03	2.98	1.49
2.2324	2	2	0.2	0.03	0.49	0.17	0.10	0.62	0.06	2.95	1.48
2.3094	2	2	0.2	0.16	0.69	0.30	0.25	0.68	0.11	3.03	1.51
2.3864	2	2	0.2	0.07	1.21	0.25	0.16	0.78	0.02	3.19	1.60
2.396	2	2	0.2	0.06	0.51	0.65	0.10	0.71	0.02	3.04	1.52
2.5	2	2	0.2	0.05	2.21	1.46	0.23	0.84	0.16	3.98	2.00
2.6444	2	2	0.2	0.05	1.09	1.17	0.25	0.64	0.10	3.33	1.66
2.6464	2	2	0.2	0.20	1.04	1.15	0.03	0.83	0.01	3.34	1.67
2.7	2	2	0.2	0.04	6.53	1.45	0.68	0.70	0.14	7.33	3.62
2.8	2	2	0.2	0.04	0.21	1.69	1.92	0.59	0.26	3.88	1.94
2.9	2	2	0.2	0.07	0.84	0.75	0.11	0.86	0.34	3.19	1.60
2.95	2	2	0.2	0.03	1.13	1.12	0.66	0.90	0.06	3.44	1.72
2.981	2	2	0.2	0.03	1.80	2.37	0.48	0.59	0.16	4.18	2.10
3	2	2	0.2	0.03	1.20	1.74	0.94	0.70	0.16	3.73	1.86
3.02	2	2	0.2	0.02	2.66	1.64	0.41	0.71	0.02	4.30	2.14
3.08	2	2	0.2	0.03	0.87	0.95	0.81	0.60	0.30	3.28	1.64

Systematic uncertainty in $|G_E/G_M|$

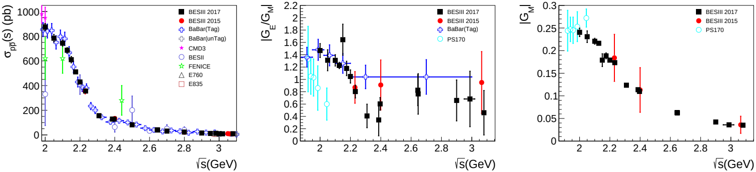
- Summary of systematic uncertainties in $|G_E/G_M|$ and $|G_M|$ measurement as the table below:

$\sqrt{s}$ (GeV)	Δ_R^{eff} [%]	Δ_R^{TOF} [%]	Δ_R^{angle} [%]	Δ_R^{p} [%]	Δ_R^{bkg} [%]	Δ_R^{model} [%]	Δ_R^{symm} [%]	Δ_R^{tot} [%]	$\Delta_{\lvert G_M\rvert}^{tot}$ [%]
2	0.48	0.47	0.60	0.79	0.25	0.67	0.60	1.52	0.88
2.05	0.08	0.47	0.08	2.05	0.40	0.00	1.36	2.54	1.17
2.1	0.71	0.30	0.25	1.10	0.60	0.45	0.45	1.62	0.83
2.12655	2.44	0.18	0.83	0.04	0.26	0.26	0.44	2.65	1.04
2.15	0.03	0.63	1.50	2.65	0.25	0.10	0.37	3.14	1.94
2.175	2.61	0.57	0.90	1.80	0.79	0.26	0.75	3.53	1.30
2.2	1.09	0.23	1.66	0.59	0.12	0.15	0.49	2.15	0.53
2.2324	1.00	0.06	0.98	0.37	0.67	0.07	0.50	1.67	0.60
2.3094	2.72	1.96	2.28	2.39	0.44	1.30	0.60	4.94	0.57
2.3864	3.25	1.29	1.83	0.37	0.37	0.29	0.83	4.07	0.72
2.396	0.15	0.56	1.44	0.91	1.05	0.47	0.79	2.28	0.58
2.6444	0.26	0.04	1.82	0.19	2.16	1.64	0.87	3.39	1.17
2.6464	0.14	4.24	1.16	1.48	1.49	0.18	0.96	4.97	1.07
2.9	0.90	3.52	2.49	2.05	5.16	1.18	1.79	7.41	1.03
2.988	4.22	0.03	2.83	0.63	0.97	5.75	0.78	7.80	0.87
3.08	0.35	2.39	2.71	2.79	1.47	1.32	1.68	5.26	0.87

Summary

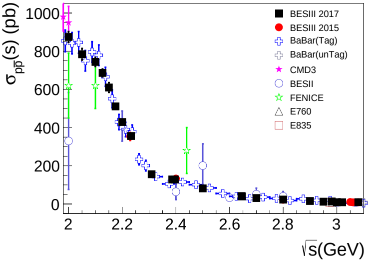
Summary

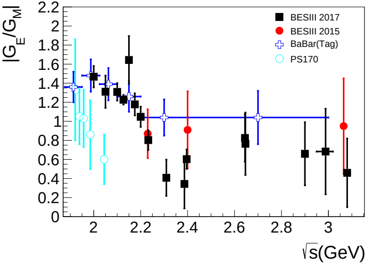
- Final results for the $\sigma_{dressed}$, $|G_E/G_M|$ and $|G_M|$.

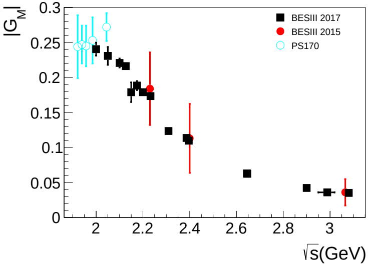


$\sqrt{s}$[GeV]	$\sigma_{dressed}$[pb]	$\lvert G\rvert[10^{-2}]$	$\lvert G_E/G_M\rvert$	$\lvert G_M\rvert[10^{-2}]$
2	$874.6 \pm 12.0 \pm 25.7$	$27.97 \pm 0.19 \pm 0.41$	$1.47 \pm 0.11 \pm 0.02$	$24.05 \pm 0.87 \pm 0.21$
2.05	$784.1 \pm 19.1 \pm 24.3$	$25.41 \pm 0.31 \pm 0.39$	$1.31 \pm 0.17 \pm 0.03$	$23.08 \pm 1.25 \pm 0.27$
2.1	$743.9 \pm 9.6 \pm 22.3$	$24.21 \pm 0.16 \pm 0.36$	$1.31 \pm 0.09 \pm 0.02$	$22.07 \pm 0.62 \pm 0.18$
2.12655	$686.3 \pm 3.1 \pm 21.0$	$23.10 \pm 0.05 \pm 0.35$	$1.23 \pm 0.03 \pm 0.03$	$21.62 \pm 0.20 \pm 0.22$
2.15	$609.9 \pm 17.7 \pm 19.6$	$21.69 \pm 0.31 \pm 0.35$	$1.64 \pm 0.24 \pm 0.05$	$17.89 \pm 1.36 \pm 0.35$
2.175	$511.1 \pm 8.3 \pm 15.9$	$19.81 \pm 0.16 \pm 0.31$	$1.18 \pm 0.11 \pm 0.04$	$18.84 \pm 0.61 \pm 0.25$
2.2	$429.1 \pm 6.7 \pm 12.8$	$18.13 \pm 0.14 \pm 0.27$	$1.05 \pm 0.10 \pm 0.02$	$17.90 \pm 0.50 \pm 0.09$
2.2324	$355.9 \pm 5.9 \pm 10.5$	$16.52 \pm 0.14 \pm 0.24$	$0.80 \pm 0.10 \pm 0.01$	$17.34 \pm 0.44 \pm 0.10$
2.3094	$155.8 \pm 3.2 \pm 4.7$	$11.00 \pm 0.11 \pm 0.17$	$0.41 \pm 0.19 \pm 0.02$	$12.35 \pm 0.32 \pm 0.07$
2.3864	$128.4 \pm 3.0 \pm 4.1$	$10.11 \pm 0.12 \pm 0.16$	$0.34 \pm 0.26 \pm 0.01$	$11.36 \pm 0.33 \pm 0.08$
2.396	$128.3 \pm 1.7 \pm 3.9$	$10.12 \pm 0.07 \pm 0.15$	$0.60 \pm 0.10 \pm 0.01$	$10.98 \pm 0.20 \pm 0.06$
2.5	$81.8 \pm 11.0 \pm 3.3$	$8.27 \pm 0.56 \pm 0.16$	–	–
2.6444	$41.2 \pm 1.4 \pm 1.4$	$6.09 \pm 0.10 \pm 0.10$	$0.83 \pm 0.25 \pm 0.03$	$6.29 \pm 0.29 \pm 0.07$
2.6464	$39.7 \pm 1.4 \pm 1.3$	$5.98 \pm 0.10 \pm 0.10$	$0.76 \pm 0.33 \pm 0.04$	$6.24 \pm 0.36 \pm 0.07$
2.7	$31.0 \pm 6.9 \pm 2.3$	$5.36 \pm 0.60 \pm 0.19$	–	–
2.8	$23.1 \pm 2.8 \pm 0.9$	$4.75 \pm 0.29 \pm 0.09$	–	–
2.9	$15.5 \pm 0.5 \pm 0.5$	$4.01 \pm 0.06 \pm 0.06$	$0.66 \pm 0.33 \pm 0.05$	$4.22 \pm 0.19 \pm 0.04$
2.95	$11.9 \pm 1.1 \pm 0.4$	$3.56 \pm 0.16 \pm 0.06$		
2.981	$13.1 \pm 1.1 \pm 0.5$	$3.77 \pm 0.16 \pm 0.08$	$0.68 \pm 0.45 \pm 0.05$	$3.59 \pm 0.22 \pm 0.03$
3	$9.4 \pm 1.0 \pm 0.4$	$3.21 \pm 0.17 \pm 0.06$		
3.02	$9.0 \pm 0.9 \pm 0.4$	$3.16 \pm 0.16 \pm 0.07$		
3.08	$9.4 \pm 0.3 \pm 0.3$	$3.29 \pm 0.06 \pm 0.05$	$0.46 \pm 0.36 \pm 0.02$	$3.51 \pm 0.12 \pm 0.03$

Summary







2.1	0.62 ± 0.18
2.12655	0.20 ± 0.22
2.15	1.36 ± 0.35
2.175	0.61 ± 0.25
2.2	0.50 ± 0.09
2.2324	0.44 ± 0.10
2.3094	0.32 ± 0.07
2.3864	0.33 ± 0.08
2.396	0.20 ± 0.06
2.5	—
2.6444	0.29 ± 0.07
2.6464	0.36 ± 0.07
2.7	—
2.8	—
2.9	0.19 ± 0.04
2.95	
2.981	0.22 ± 0.03
3	
3.02	
3.08	9.4 ± 0.3 ± 0.3 | 3.29 ± 0.06 ± 0.05 | 0.46 ± 0.30 ± 0.02 | 3.31 ± 0.12 ± 0.03

Summary

- Based on 0.688 fb^{-1}, collected at 22 center-of-mass energies between 2.0 to 3.08 GeV, we measured the cross section and effective form factor with total uncertainties ranging from 3.0% to 23.5% and 1.7% to 11.8%.
- For the first time in the time-like region, our measurement is dominated by the systematic uncertainty for most scan points at low to medium energy, providing an unprecedented accuracy.
- For both cross section and effective form factor, there is a good agreement with existing measurements. The structure in the cross section observed by BaBar around 3.0 GeV can not be observed, while the one around 2.25 GeV cannot be resolved with our measurement.
- The form factor ratio $|G_E/G_M|$ was measured with total uncertainties around 10% for scan points of low to intermediate energy, providing an uncertainty comparable to the space-like region for the first time.

Summary

- Our measurement of $|G_E/G_M|$ strongly favors BaBar's compared to that of PS170.
- $|G_M|$ was measured for the first time over a wide range of energy with uncertainties of 1.8% to 3.6%, greatly improving the uncertainty of previous measurements.

Thanks all for hard work!

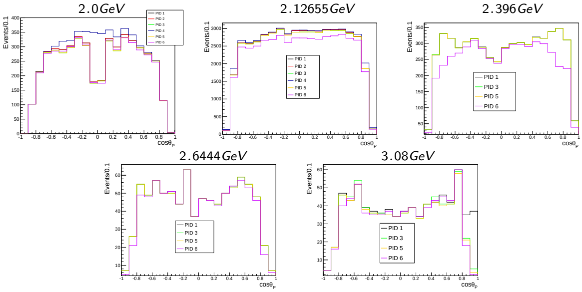
Thanks for your attention!

Backup

Backup

PID comparison

- To optimize the Bhabha rejection at each center-of-mass energy we studied different PID choices:
  - PID1: $Prob(p) > Prob(e, \pi, K)$ for both positive and negative charged tracks; Only information form the TOF and the MDC used in the PID system.
  - PID2: $Prob(p) > Prob(\pi, K)$, $Prob(p) > 10 \times Prob(e)$ for both positive and negative charged tracks;



$\cos\theta_p$ distributions after different PID choices.

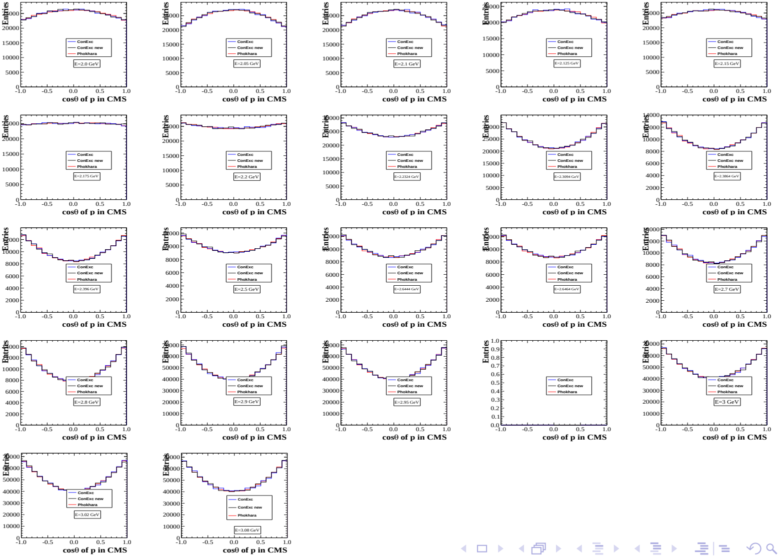
PID comparison

- PID3: $Prob(p) > Prob(\pi, K)$ for both positive and negative charged tracks and $E/p < 0.5$ for positive charged track. If the positive track does not hit EMC, the event is not rejected, except at the center-of mass energy of 3.08 GeV due to high Bhabha contamination;
- PID4: $normPH > CUT$ of both positive and negative charged tracks;
  $CUT = (3.0, 2.5, 2.0, 1, 8, 1.7, 1.7, 1.5, 1.5, 1.4, 1.265)$ at (2.0,2.05,2.1,2.12655,2.175,2.2,2.2324,2.3094,2.3864,2.396) GeV.
- PID5: $Prob(p) > Prob(e, \pi, K)$ for both positive and negative charged tracks, and $E/p < 0.5$ for positive charged track, If the positive track does not hit EMC the event is not rejected;
- PID6: Like PID1 but including the use of EMC information in the PID system.

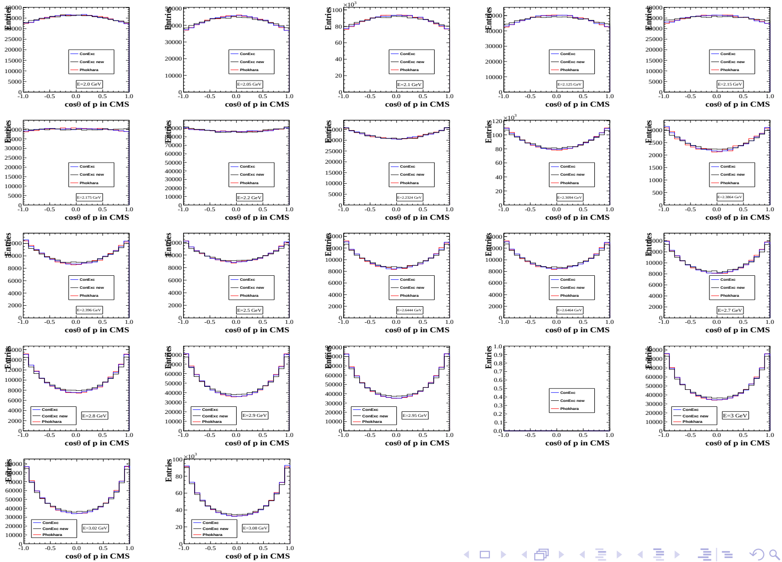
Generator Comparision

- We have two generators for $e^+e^- \to p\bar{p}$ simulation, PHOKHARA and ConExc.
- For ConExc, we have two versions:
  BesEvtGen-00-03-18 and BesEvtGen-00-03-69
  So in total, we compare three generators, namely: PHOKHARA, ConExc-18 and ConExc-69.
- In the following, we call them ConExc (BesEvtGen-00-03-18), conexc new (BesEvtGen-00-03-69), and PHOKHARA.
- We compare them using the MCTruth information, that is before detector simulation.

$cos\theta$ of born events



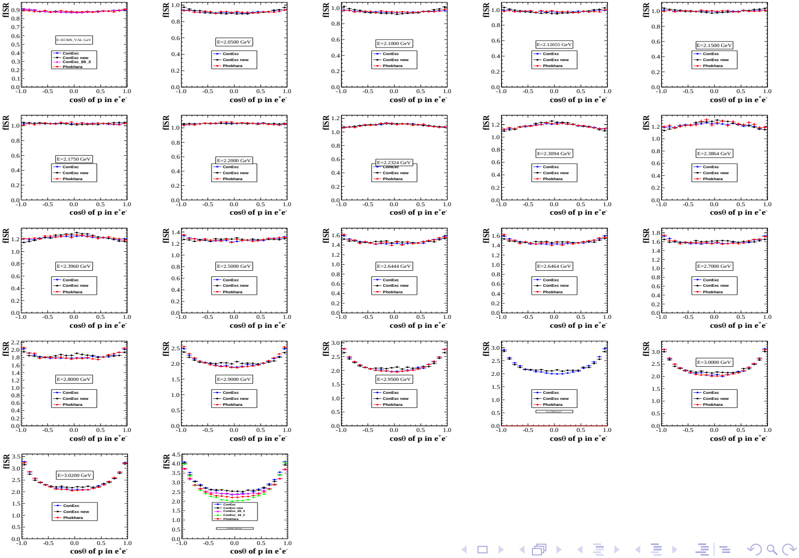
$cos\theta$ of born+NLO events



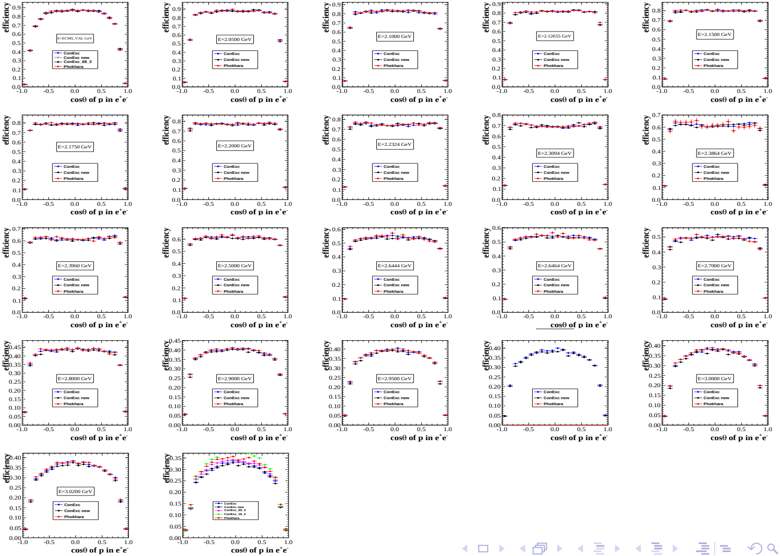
$(1+\delta)(cos\theta)$ curves

Measurement of Proton Electromagnetic Form Factors

Ch. Rosner & L. Xia et al



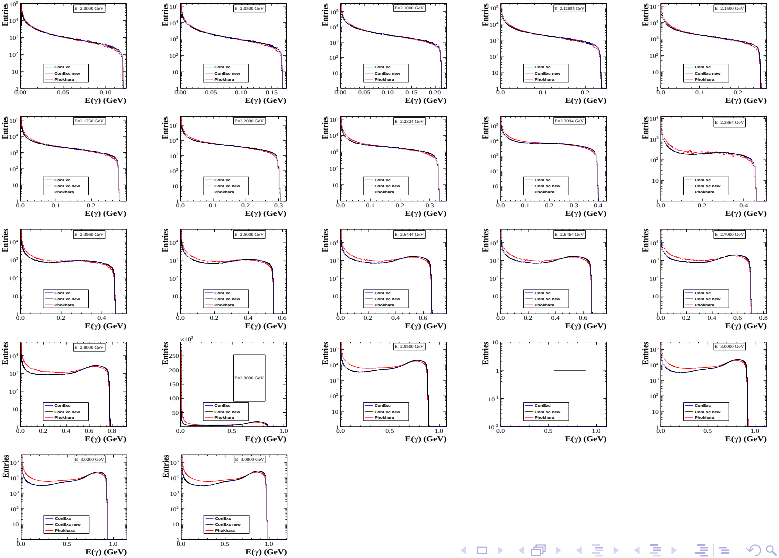
$\epsilon(cos\theta)$ curves



Reasons?

- The input are almost the same, either σ_{Born} or $\frac{d\sigma_{Born}}{d\cos\theta}$.
- The output after considering ISR (NLO), the distributions of $\frac{d\sigma_{Born}}{d\cos\theta}$ are different.
- the I/O check for R and Gm values?
- the details about angular distributions?

$E(\gamma)$ curves



$cos\theta(\gamma)$ curves

Measurement of Proton Electromagnetic Form Factors

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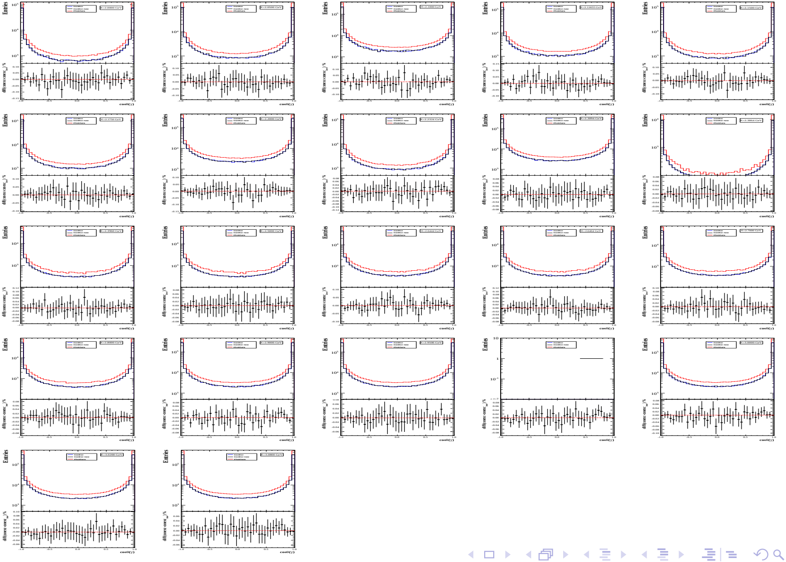
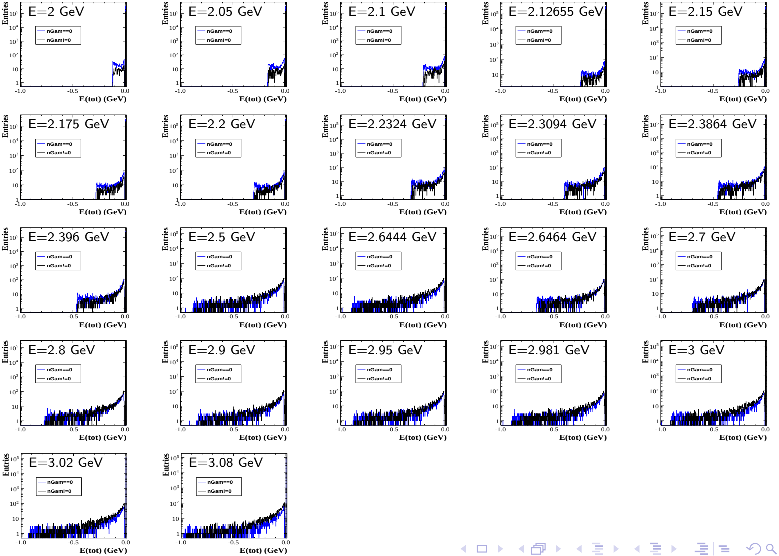
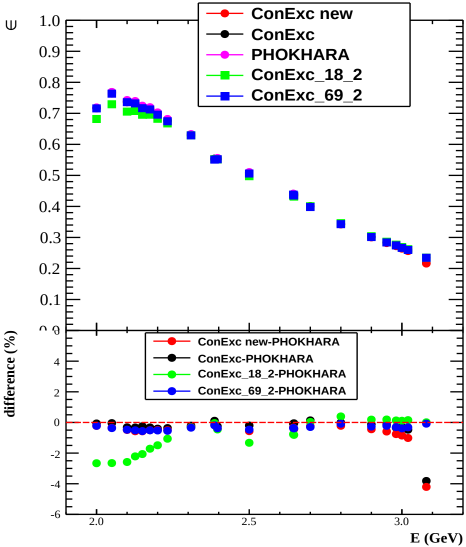


MCTruth of E_{tot} from ConExc_new



Total efficiency and difference



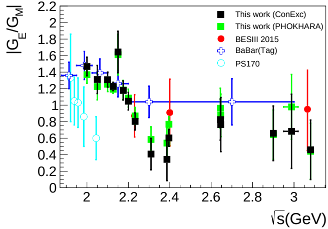
Total efficiency and difference

- Total efficiency and difference:
  - diff=$(\epsilon_{Phokhara} - \epsilon_{ConExc})/average$;
  - diff new= $(\epsilon_{Phokhara} - \epsilon_{ConExcnew})/average$.

E (GeV)	$\epsilon_{Phokhara}$	ϵ_{ConExc}	diff (%)	$\epsilon_{ConExcnew}$	diff new
2.0	0.719 ± 0.001	0.718 ± 0.001	-0.065	0.716 ± 0.001	-0.225
2.05	0.769 ± 0.000	0.768 ± 0.001	-0.043	0.764 ± 0.001	-0.351
2.1	0.743 ± 0.000	0.738 ± 0.001	-0.319	0.736 ± 0.001	-0.490
2.125	0.740 ± 0.000	0.735 ± 0.001	-0.333	0.731 ± 0.001	-0.573
2.15	0.725 ± 0.001	0.722 ± 0.001	-0.179	0.716 ± 0.001	-0.577
2.175	0.720 ± 0.001	0.716 ± 0.001	-0.259	0.713 ± 0.001	-0.505
2.2	0.703 ± 0.000	0.698 ± 0.001	-0.335	0.696 ± 0.001	-0.493
2.2324	0.682 ± 0.001	0.678 ± 0.001	-0.319	0.675 ± 0.001	-0.502
2.3094	$- \pm -$	0.631 ± 0.001	$-$	0.630 ± 0.001	$-$
2.3864	0.553 ± 0.002	0.554 ± 0.001	0.109	0.551 ± 0.001	-0.150
2.396	0.556 ± 0.001	0.553 ± 0.001	-0.256	0.552 ± 0.001	-0.415
2.5	0.511 ± 0.001	0.509 ± 0.001	-0.201	0.505 ± 0.001	-0.568
2.6444	0.441 ± 0.001	0.441 ± 0.001	-0.085	0.438 ± 0.001	-0.333
2.6464	0.439 ± 0.001	0.438 ± 0.001	-0.055	0.435 ± 0.001	-0.434
2.7	0.400 ± 0.001	0.401 ± 0.001	0.134	0.398 ± 0.001	-0.245
2.8	0.343 ± 0.001	0.343 ± 0.001	-0.011	0.342 ± 0.001	-0.217
2.9	0.303 ± 0.000	0.302 ± 0.001	-0.128	0.300 ± 0.001	-0.442
2.95	0.285 ± 0.000	0.284 ± 0.001	-0.143	0.282 ± 0.001	-0.592
2.981	0.000 ± 0.000	0.274 ± 0.001	100.00	0.272 ± 0.001	100.00
3	0.268 ± 0.000	0.267 ± 0.001	-0.297	0.264 ± 0.001	-0.853
3.02	0.261 ± 0.000	0.259 ± 0.001	-0.473	0.256 ± 0.001	-1.013
3.08	0.235 ± 0.000	0.218 ± 0.001	-3.818	0.216 ± 0.001	-4.206

Results of electromagnetic form factors

- The figure shows G_E/G_M of proton, compared with BESIII 2015 PRD **91**, 112004 (2015), BaBar PRD **87**, 092005 (2013), PS170 Nucl. Phys. **B411** (1994) 3
  The table summarizes the results using the two different methods and the two generators.



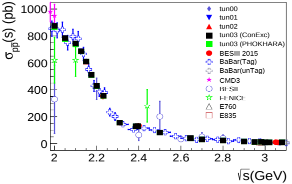
$\sqrt{s}$(GeV)	Fit on the proton angular distribution				Method of Moments			
	ConExc		PHOKHARA		ConExc		PHOKHARA	
	$\|G_E/G_M\|$	$\|G_M\|$ (10^{-2})	$\|G_E/G_M\|$	$\|G_M\|$ (10^{-2})	$\|G_E/G_M\|$	$\|G_M\|$ (10^{-2})	$\|G_E/G_M\|$	$\|G_M\|$ (10^{-2})
2	1.47 ± 0.11	24.05 ± 0.87	1.37 ± 0.10	24.71 ± 0.83	1.47 ± 0.10	24.00 ± 0.83	1.38 ± 0.10	24.66 ± 0.79
2.05	1.31 ± 0.17	23.08 ± 1.25	1.23 ± 0.16	23.59 ± 1.20	1.28 ± 0.16	23.31 ± 1.21	1.19 ± 0.15	23.81 ± 1.17
2.1	1.31 ± 0.09	22.07 ± 0.62	1.25 ± 0.09	22.35 ± 0.60	1.32 ± 0.09	21.98 ± 0.61	1.27 ± 0.08	22.24 ± 0.60
2.12655	1.23 ± 0.03	21.62 ± 0.20	1.19 ± 0.03	21.82 ± 0.20	1.22 ± 0.03	21.64 ± 0.20	1.19 ± 0.03	21.82 ± 0.19
2.15	1.64 ± 0.24	17.89 ± 1.36	1.61 ± 0.24	18.09 ± 1.35	1.59 ± 0.23	18.21 ± 1.33	1.56 ± 0.23	18.35 ± 1.32
2.175	1.18 ± 0.11	18.84 ± 0.61	1.18 ± 0.11	18.77 ± 0.60	1.19 ± 0.11	18.78 ± 0.60	1.20 ± 0.11	18.69 ± 0.60
2.2	1.05 ± 0.10	17.90 ± 0.50	1.09 ± 0.10	17.69 ± 0.50	1.07 ± 0.10	17.77 ± 0.49	1.11 ± 0.10	17.55 ± 0.50
2.2324	0.80 ± 0.10	17.34 ± 0.44	0.87 ± 0.10	17.06 ± 0.45	0.83 ± 0.10	17.23 ± 0.44	0.90 ± 0.10	16.94 ± 0.45
2.3094	0.41 ± 0.19	12.35 ± 0.32	0.58 ± 0.15	12.03 ± 0.34	0.39 ± 0.20	12.38 ± 0.32	0.58 ± 0.15	12.04 ± 0.34
2.3864	0.34 ± 0.26	11.36 ± 0.33	0.54 ± 0.19	11.05 ± 0.34	0.33 ± 0.27	11.38 ± 0.33	0.54 ± 0.19	11.06 ± 0.34
2.396	0.60 ± 0.10	10.98 ± 0.20	0.77 ± 0.09	10.63 ± 0.21	0.63 ± 0.10	10.92 ± 0.20	0.79 ± 0.09	10.57 ± 0.21
2.6444	0.83 ± 0.25	6.29 ± 0.29	0.96 ± 0.24	6.12 ± 0.30	0.91 ± 0.24	6.19 ± 0.30	1.04 ± 0.24	6.02 ± 0.31
2.6464	0.76 ± 0.33	6.24 ± 0.36	0.88 ± 0.26	6.11 ± 0.31	0.73 ± 0.27	6.28 ± 0.30	0.86 ± 0.26	6.13 ± 0.31
2.9	0.66 ± 0.33	4.22 ± 0.19	0.64 ± 0.29	4.22 ± 0.17	0.34 ± 0.48	4.35 ± 0.16	0.64 ± 0.30	4.22 ± 0.17
2.988	0.68 ± 0.45	3.59 ± 0.22	0.98 ± 0.38	3.45 ± 0.23	0.78 ± 0.43	3.55 ± 0.23	1.04 ± 0.39	3.41 ± 0.24
3.08	0.46 ± 0.36	3.51 ± 0.12	0.44 ± 0.34	3.53 ± 0.11	$- \pm -$	$- \pm -$	$- \pm -$	$- \pm -$

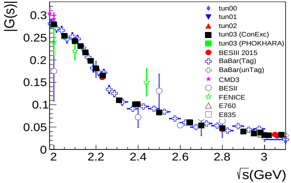
Tuning of cross section and effective form factor

Measurement of Proton Electromagnetic Form Factors

Ch. Rosner & L. Xia et al

- The systematic uncertainty, Δ, is defined as the nearest relative difference with respect to the nominal results.

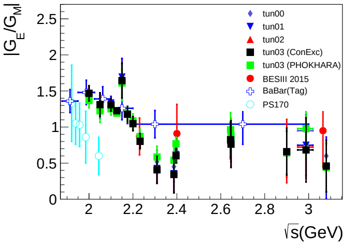




$\sqrt{s}$[GeV]	σ_{born}^{result} [GeV]	σ_{born}^{tun2}[pb]	σ_{born}^{tun1}[pb]	σ_{born}^{ini}[pb]	Δ_{σ}^{model}	$\lvert G\rvert^{result}[10^{-2}]$	$\lvert G\rvert^{tun2}[10^{-2}]$	$\lvert G\rvert^{tun1}[10^{-2}]$	$\lvert G\rvert^{ini}[10^{-2}]$	$\Delta_{\lvert G\rvert}^{bkg}$
2	874.552 ± 12.035	875.681 ± 12.064	875.506 ± 12.057	874.372 ± 12.046	0.13%	27.97 ± 0.19	27.99 ± 0.19	27.98 ± 0.19	27.97 ± 0.19	0.06%
2.05	784.082 ± 19.054	784.679 ± 19.075	784.172 ± 19.051	783.520 ± 19.030	0.08%	25.41 ± 0.31	25.42 ± 0.31	25.41 ± 0.31	25.40 ± 0.31	0.04%
2.1	743.886 ± 9.629	744.029 ± 9.641	744.216 ± 9.643	742.618 ± 9.623	0.02%	24.21 ± 0.16	24.21 ± 0.16	24.22 ± 0.16	24.19 ± 0.16	0.01%
2.12655	686.303 ± 3.108	686.913 ± 3.140	686.886 ± 3.139	685.678 ± 3.134	0.09%	23.10 ± 0.05	23.11 ± 0.05	23.11 ± 0.05	23.09 ± 0.05	0.04%
2.15	609.945 ± 17.695	609.262 ± 17.679	609.751 ± 17.693	614.150 ± 17.821	0.11%	21.69 ± 0.31	21.68 ± 0.31	21.69 ± 0.31	21.77 ± 0.32	0.06%
2.175	511.129 ± 8.340	510.985 ± 8.343	511.026 ± 8.345	511.630 ± 8.361	0.03%	19.81 ± 0.16	19.80 ± 0.16	19.81 ± 0.16	19.82 ± 0.16	0.01%
2.2	429.121 ± 6.719	429.232 ± 6.726	428.526 ± 6.715	429.124 ± 6.724	0.03%	18.13 ± 0.14	18.13 ± 0.14	18.12 ± 0.14	18.13 ± 0.14	0.01%
2.2324	355.908 ± 5.903	356.104 ± 5.911	355.445 ± 5.900	356.598 ± 5.919	0.06%	16.52 ± 0.14	16.52 ± 0.14	16.51 ± 0.14	16.53 ± 0.14	0.03%
2.3094	155.815 ± 3.231	155.640 ± 3.229	155.394 ± 3.224	152.908 ± 3.172	0.11%	11.00 ± 0.11	10.99 ± 0.11	10.99 ± 0.11	10.90 ± 0.11	0.06%
2.3864	128.408 ± 2.986	128.388 ± 2.987	128.195 ± 2.983	126.718 ± 2.949	0.02%	10.11 ± 0.12	10.11 ± 0.12	10.10 ± 0.12	10.04 ± 0.12	0.01%
2.396	128.319 ± 1.732	128.290 ± 1.734	128.103 ± 1.731	126.755 ± 1.714	0.02%	10.12 ± 0.07	10.12 ± 0.07	10.12 ± 0.07	10.06 ± 0.07	0.01%
2.5	81.846 ± 11.036	81.719 ± 11.019	81.674 ± 11.013	81.478 ± 10.987	0.16%	8.27 ± 0.56	8.26 ± 0.56	8.26 ± 0.56	8.25 ± 0.56	0.08%
2.6444	41.249 ± 1.401	41.289 ± 1.402	41.273 ± 1.401	41.333 ± 1.403	0.10%	6.09 ± 0.10	6.09 ± 0.10	6.09 ± 0.10	6.09 ± 0.10	0.05%
2.6464	39.746 ± 1.372	39.751 ± 1.373	39.726 ± 1.372	39.742 ± 1.372	0.01%	5.98 ± 0.10	5.98 ± 0.10	5.98 ± 0.10	5.98 ± 0.10	0.01%
2.7	31.007 ± 6.933	30.963 ± 6.924	30.936 ± 6.918	30.913 ± 6.912	0.14%	5.36 ± 0.60	5.35 ± 0.60	5.35 ± 0.60	5.35 ± 0.60	0.07%
2.8	23.107 ± 2.802	23.047 ± 2.795	23.023 ± 2.792	22.639 ± 2.746	0.26%	4.75 ± 0.29	4.75 ± 0.29	4.75 ± 0.29	4.71 ± 0.29	0.13%
2.9	15.529 ± 0.488	15.476 ± 0.487	15.405 ± 0.485	14.991 ± 0.472	0.34%	4.01 ± 0.06	4.00 ± 0.06	3.99 ± 0.06	3.94 ± 0.06	0.17%
2.95	11.932 ± 1.099	11.926 ± 1.098	11.839 ± 1.090	11.544 ± 1.063	0.06%	3.56 ± 0.16	3.56 ± 0.16	3.55 ± 0.16	3.51 ± 0.16	0.03%
2.981	13.128 ± 1.143	13.107 ± 1.141	13.026 ± 1.134	12.624 ± 1.103	0.16%	3.77 ± 0.16	3.77 ± 0.16	3.76 ± 0.16	3.70 ± 0.16	0.08%
3	9.396 ± 0.974	9.382 ± 0.973	9.324 ± 0.967	9.098 ± 0.943	0.16%	3.21 ± 0.17	3.20 ± 0.17	3.19 ± 0.17	3.16 ± 0.16	0.08%
3.02	9.025 ± 0.916	9.027 ± 0.917	8.971 ± 0.911	8.685 ± 0.882	0.02%	3.16 ± 0.16	3.16 ± 0.16	3.15 ± 0.16	3.10 ± 0.16	0.01%
3.08	9.438 ± 0.323	9.410 ± 0.322	9.367 ± 0.321	8.970 ± 0.306	0.30%	3.29 ± 0.06	3.28 ± 0.06	3.28 ± 0.06	3.21 ± 0.05	0.15%

Tuning of cross section and effective form factor

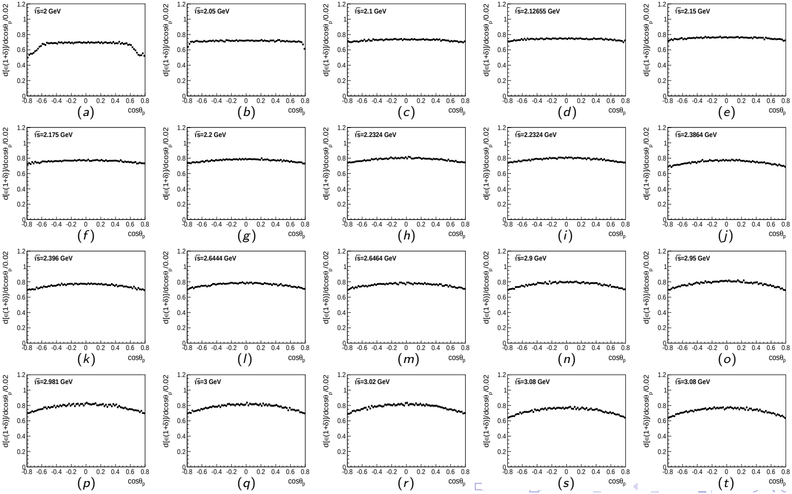
- $|G_E/G_M|$ and $|G_M|$ after the initial MC model and the first and second iteration (our nominal result). The systematic uncertainty, Δ, is defined as the largest relative difference with respect to the nominal results.



$\sqrt{s}$[GeV]	$\lvert G_E/G_M\rvert^{result}$	$\lvert G_E/G_M\rvert^{tun2}$	$\lvert G_E/G_M\rvert^{tun1}$	$\lvert G_E/G_M\rvert^{ini}$	Δ_R^{model}	$\lvert G_M\rvert^{result}[10^{-2}]$	$\lvert G_M\rvert^{tun2}[10^{-2}]$	$\lvert G_M\rvert^{tun1}[10^{-2}]$	$\lvert G_M\rvert^{ini}[10^{-2}]$	$\Delta_{\lvert G_M\rvert}^{model}$
2	1.468 ± 0.107	1.458 ± 0.106	1.439 ± 0.107	1.431 ± 0.107	0.67%	24.05 ± 0.87	24.14 ± 0.87	24.29 ± 0.88	24.34 ± 0.88	0.39%
2.05	1.311 ± 0.165	1.311 ± 0.165	1.287 ± 0.166	1.284 ± 0.165	0.00%	23.08 ± 1.25	23.09 ± 1.25	23.25 ± 1.26	23.27 ± 1.25	0.04%
2.1	1.309 ± 0.088	1.315 ± 0.089	1.333 ± 0.091	1.336 ± 0.091	0.45%	22.07 ± 0.62	22.03 ± 0.62	21.91 ± 0.63	21.86 ± 0.63	0.17%
2.12655	1.226 ± 0.030	1.229 ± 0.031	1.222 ± 0.031	1.231 ± 0.031	0.26%	21.62 ± 0.20	21.61 ± 0.21	21.66 ± 0.21	21.58 ± 0.21	0.05%
2.15	1.644 ± 0.242	1.645 ± 0.243	1.693 ± 0.255	1.698 ± 0.256	0.10%	17.89 ± 1.36	17.88 ± 1.36	17.62 ± 1.41	17.66 ± 1.42	0.10%
2.175	1.178 ± 0.107	1.181 ± 0.108	1.155 ± 0.108	1.162 ± 0.108	0.26%	18.84 ± 0.61	18.82 ± 0.61	18.96 ± 0.61	18.94 ± 0.61	0.10%
2.2	1.047 ± 0.098	1.049 ± 0.098	1.051 ± 0.099	1.047 ± 0.099	0.15%	17.90 ± 0.50	17.89 ± 0.50	17.87 ± 0.50	17.90 ± 0.50	0.03%
2.2324	0.803 ± 0.103	0.802 ± 0.104	0.816 ± 0.104	0.806 ± 0.105	0.07%	17.34 ± 0.44	17.35 ± 0.44	17.28 ± 0.44	17.34 ± 0.44	0.04%
2.3094	0.408 ± 0.189	0.413 ± 0.188	0.426 ± 0.186	0.520 ± 0.164	1.30%	12.35 ± 0.32	12.34 ± 0.33	12.31 ± 0.33	12.04 ± 0.33	0.12%
2.3864	0.343 ± 0.256	0.344 ± 0.256	0.354 ± 0.251	0.451 ± 0.209	0.29%	11.36 ± 0.33	11.36 ± 0.33	11.34 ± 0.33	11.15 ± 0.33	0.02%
2.396	0.603 ± 0.102	0.606 ± 0.102	0.617 ± 0.101	0.682 ± 0.096	0.47%	10.98 ± 0.20	10.97 ± 0.20	10.94 ± 0.20	10.76 ± 0.20	0.06%
2.6444	0.825 ± 0.246	0.812 ± 0.248	0.814 ± 0.248	0.803 ± 0.249	1.64%	6.29 ± 0.29	6.31 ± 0.29	6.31 ± 0.29	6.32 ± 0.29	0.29%
2.6464	0.764 ± 0.326	0.763 ± 0.300	0.778 ± 0.266	0.783 ± 0.265	0.18%	6.24 ± 0.36	6.25 ± 0.33	6.23 ± 0.30	6.22 ± 0.30	0.03%
2.9	0.659 ± 0.327	0.667 ± 0.440	0.625 ± 0.320	0.647 ± 0.296	1.18%	4.22 ± 0.19	4.21 ± 0.25	4.22 ± 0.18	4.15 ± 0.17	0.27%
2.988	0.683 ± 0.445	0.722 ± 0.433	0.748 ± 0.424	0.950 ± 0.386	5.75%	3.59 ± 0.22	3.57 ± 0.22	3.55 ± 0.22	3.40 ± 0.22	0.54%
3.08	0.460 ± 0.359	0.466 ± 0.358	0.433 ± 0.428	0.600 ± 0.168	1.32%	3.51 ± 0.12	3.50 ± 0.12	3.51 ± 0.13	3.38 ± 0.08	0.20%

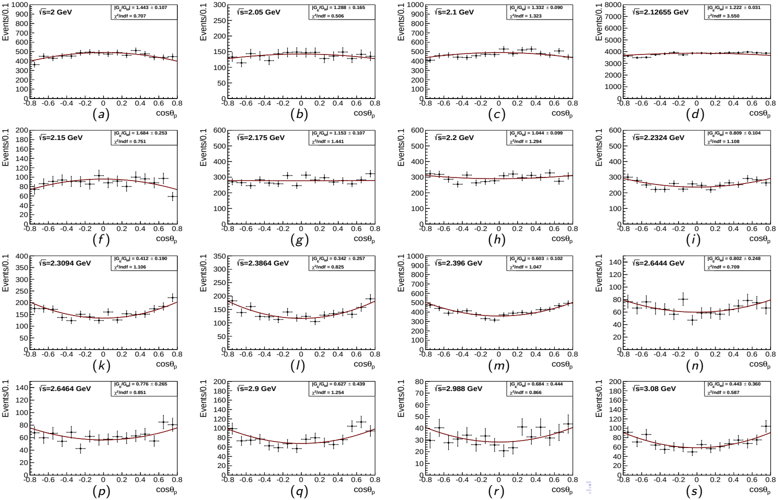
ISR-Efficiency correction

- $\epsilon(1+\delta)$ curves at different center-of-mass energies in the last round of iteration.



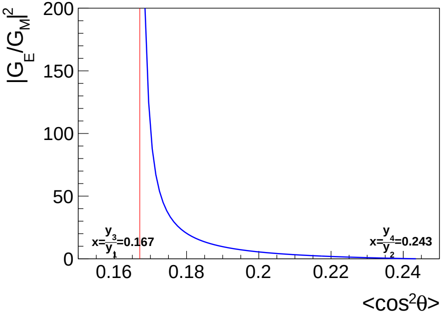
Fit for angular distribution of proton

- Fit on $\cos\theta_p$ distributions from data corrected by $\epsilon(1+\delta)$ curves at each energy point.



$< \cos^2\theta >$ range

- $y_3/y_1 << \cos^2\theta >< y_4/y_2$ is the promise of application Method of Moments (MM).
- We don't have $|G_E/G_M|$ result of Method of Moments (MM) at 3.08 GeV while the $< \cos^2\theta >> y_4/y_2$ from such few events to analysis.



$|G_E/G_M|^2$-$< \cos^2\theta >$ distribution.

Tracking efficiency

- The signal number and tracking efficiency on the transverse momentum distribution of for tracking efficiency of recoil proton.

p_t[GeV]	n_p(data)	N_p(data)	ϵ_{Track}(data) [%]	n_p(MC)	N_p(MC)	ϵ_{Track}(MC) [%]	1-Δ_{Track}
0.1-0.2	538 ± 24	1689 ± 49	31.827 ± 1.257	66380 ± 258	213653 ± 462	31.069 ± 0.100	0.976 ± 0.039
0.2-0.3	2742 ± 60	3069 ± 62	89.330 ± 0.570	326992 ± 572	364104 ± 603	89.807 ± 0.050	1.005 ± 0.006
0.3-0.4	3512 ± 66	3582 ± 70	98.051 ± 0.681	401056 ± 633	408454 ± 639	98.189 ± 0.021	1.001 ± 0.007
0.4-0.5	3059 ± 63	3096 ± 65	98.815 ± 0.594	370267 ± 608	374344 ± 612	98.911 ± 0.017	1.001 ± 0.006
0.5-0.6	2462 ± 56	2483 ± 57	99.141 ± 0.345	300428 ± 548	303017 ± 550	99.146 ± 0.017	1.000 ± 0.003
0.6-0.7	1542 ± 47	1553 ± 45	99.231 ± 0.880	211762 ± 460	213403 ± 462	99.231 ± 0.019	1.000 ± 0.009
0.7-0.8	860 ± 32	866 ± 37	99.408 ± 2.121	125620 ± 354	126525 ± 356	99.285 ± 0.024	0.999 ± 0.021
0.8-0.9	279 ± 20	280 ± 24	99.670 ± 4.727	55177 ± 235	55558 ± 236	99.314 ± 0.035	0.996 ± 0.047

- The signal number and tracking efficiency on the transverse momentum distribution of for tracking efficiency of recoil anti-proton.

p_t[GeV]	$n_{\bar{p}}$(data)	$N_{\bar{p}}$(data)	ϵ_{Track}(data) [%]	$n_{\bar{p}}$(MC)	$N_{\bar{p}}$(MC)	ϵ_{Track}(MC) [%]	1-Δ_{Track}
0.1-0.2	514 ± 27	1456 ± 49	35.321 ± 1.562	62695 ± 250	177834 ± 422	35.255 ± 0.113	0.998 ± 0.044
0.2-0.3	2764 ± 59	3188 ± 74	86.712 ± 1.252	325460 ± 570	378112 ± 615	86.075 ± 0.056	0.993 ± 0.014
0.3-0.4	3425 ± 66	3534 ± 71	96.935 ± 0.675	414118 ± 644	428309 ± 654	96.687 ± 0.027	0.997 ± 0.007
0.4-0.5	3063 ± 61	3133 ± 69	97.763 ± 1.034	385087 ± 621	393858 ± 628	97.773 ± 0.024	1.000 ± 0.011
0.5-0.6	2578 ± 58	2602 ± 60	99.089 ± 0.576	314609 ± 561	319916 ± 566	98.341 ± 0.023	0.992 ± 0.006
0.6-0.7	1504 ± 46	1527 ± 47	98.489 ± 0.243	224284 ± 474	227448 ± 477	98.609 ± 0.025	1.001 ± 0.002
0.7-0.8	867 ± 34	876 ± 38	98.961 ± 1.940	134067 ± 366	135642 ± 368	98.839 ± 0.029	0.999 ± 0.020
0.8-0.9	305 ± 22	309 ± 21	98.825 ± 1.879	58214 ± 241	58831 ± 243	98.951 ± 0.042	1.001 ± 0.019

Tracking efficiency

- The signal number and tracking efficiency on the angular distribution of for tracking efficiency of recoil proton.

$\cos\theta_p$	n_p(data)	N_p(data)	ϵ_{Track}(data) [%]	n_p(MC)	N_p(MC)	ϵ_{Track}(MC) [%]	1-Δ_{Track}
-1.0--0.9	120 ± 14	220 ± 16	54.754 ± 3.435	19223 ± 139	65204 ± 255	29.481 ± 0.179	0.538 ± 0.034
-0.9--0.8	625 ± 29	757 ± 33	82.551 ± 1.784	81053 ± 285	97646 ± 312	83.007 ± 0.120	1.006 ± 0.022
-0.8--0.7	760 ± 32	855 ± 34	88.923 ± 1.259	93814 ± 306	105462 ± 325	88.955 ± 0.097	1.000 ± 0.014
-0.7--0.6	786 ± 30	865 ± 32	90.853 ± 1.233	98895 ± 314	109104 ± 330	90.643 ± 0.088	0.998 ± 0.014
-0.6--0.5	847 ± 29	925 ± 37	91.593 ± 2.214	103651 ± 322	113393 ± 337	91.409 ± 0.083	0.998 ± 0.024
-0.5--0.4	816 ± 32	890 ± 34	91.691 ± 1.283	105683 ± 325	114780 ± 339	92.074 ± 0.080	1.004 ± 0.014
-0.4--0.3	802 ± 28	869 ± 31	92.297 ± 1.461	106655 ± 327	115492 ± 340	92.348 ± 0.078	1.001 ± 0.016
-0.3--0.2	800 ± 33	863 ± 33	92.728 ± 0.472	106731 ± 327	115297 ± 340	92.570 ± 0.077	0.998 ± 0.005
-0.2--0.1	782 ± 30	844 ± 33	92.687 ± 1.444	107123 ± 327	115534 ± 340	92.720 ± 0.076	1.000 ± 0.016
-0.1-0.0	866 ± 32	933 ± 33	92.876 ± 1.087	107439 ± 328	115973 ± 341	92.641 ± 0.077	0.997 ± 0.012
0.0-0.1	871 ± 30	938 ± 34	92.862 ± 1.571	107301 ± 328	116057 ± 341	92.455 ± 0.078	0.996 ± 0.017
0.1-0.2	885 ± 33	959 ± 35	92.241 ± 1.166	107116 ± 327	115603 ± 340	92.658 ± 0.077	1.005 ± 0.013
0.2-0.3	877 ± 36	951 ± 35	92.164 ± 1.091	106948 ± 327	115809 ± 340	92.349 ± 0.078	1.002 ± 0.012
0.3-0.4	914 ± 30	991 ± 38	92.262 ± 2.157	107107 ± 327	115901 ± 340	92.412 ± 0.078	1.002 ± 0.023
0.4-0.5	881 ± 30	958 ± 35	91.929 ± 1.780	105289 ± 324	114533 ± 338	91.929 ± 0.080	1.000 ± 0.019
0.5-0.6	847 ± 29	925 ± 34	91.553 ± 1.813	103149 ± 321	112766 ± 336	91.472 ± 0.083	0.999 ± 0.020
0.6-0.7	839 ± 33	927 ± 34	90.472 ± 1.052	99663 ± 316	109945 ± 332	90.648 ± 0.088	1.002 ± 0.012
0.7-0.8	825 ± 29	926 ± 36	89.071 ± 2.175	93514 ± 306	104905 ± 324	89.142 ± 0.096	1.001 ± 0.024
0.8-0.9	734 ± 35	877 ± 39	83.693 ± 1.776	82286 ± 287	97883 ± 313	84.066 ± 0.117	1.004 ± 0.021
0.9-1.0	155 ± 16	254 ± 20	60.781 ± 3.769	19611 ± 140	64743 ± 254	30.291 ± 0.181	0.498 ± 0.031

Tracking efficiency

- The signal number and tracking efficiency on the angular distribution of for tracking efficiency of recoil anti-proton.

$\cos\theta_{\bar{p}}$	$n_{\bar{p}}$(data)	$N_{\bar{p}}$(data)	ϵ_{Track}(data) [%]	$n_{\bar{p}}$(MC)	$N_{\bar{p}}$(MC)	ϵ_{Track}(MC) [%]	1-Δ_{Track}
−1.0-−0.9	161 ± 16	260 ± 25	61.693 ± 5.076	18052 ± 134	66623 ± 258	27.096 ± 0.172	0.439 ± 0.036
−0.9-−0.8	727 ± 31	909 ± 40	80.011 ± 2.243	80820 ± 284	101103 ± 318	79.938 ± 0.126	0.999 ± 0.028
−0.8-−0.7	823 ± 31	923 ± 40	89.216 ± 2.488	96983 ± 311	108585 ± 330	89.315 ± 0.094	1.001 ± 0.028
−0.7-−0.6	836 ± 34	918 ± 38	91.037 ± 1.783	102844 ± 321	112645 ± 336	91.299 ± 0.084	1.003 ± 0.020
−0.6-−0.5	857 ± 32	930 ± 39	92.167 ± 2.245	107053 ± 327	115830 ± 340	92.423 ± 0.078	1.003 ± 0.024
−0.5-−0.4	850 ± 34	919 ± 37	92.524 ± 1.580	109956 ± 332	118408 ± 344	92.862 ± 0.075	1.004 ± 0.017
−0.4-−0.3	893 ± 37	956 ± 39	93.415 ± 1.195	111174 ± 333	119130 ± 345	93.322 ± 0.072	0.999 ± 0.013
−0.3-−0.2	867 ± 37	926 ± 37	93.692 ± 0.501	111583 ± 334	119234 ± 345	93.583 ± 0.071	0.999 ± 0.005
−0.2-−0.1	856 ± 32	915 ± 34	93.465 ± 1.194	111095 ± 333	118701 ± 345	93.592 ± 0.071	1.001 ± 0.013
−0.1-0.0	844 ± 34	902 ± 35	93.572 ± 0.688	111852 ± 334	119241 ± 345	93.803 ± 0.070	1.002 ± 0.007
0.0-0.1	813 ± 34	868 ± 35	93.656 ± 0.828	111768 ± 334	119255 ± 345	93.722 ± 0.070	1.001 ± 0.009
0.1-0.2	910 ± 34	975 ± 37	93.273 ± 1.539	111999 ± 335	119545 ± 346	93.688 ± 0.070	1.004 ± 0.017
0.2-0.3	858 ± 33	916 ± 38	93.606 ± 1.890	111581 ± 334	119320 ± 345	93.514 ± 0.071	0.999 ± 0.020
0.3-0.4	792 ± 32	849 ± 35	93.228 ± 1.600	110865 ± 333	118673 ± 344	93.421 ± 0.072	1.002 ± 0.017
0.4-0.5	851 ± 36	918 ± 37	92.697 ± 0.884	109459 ± 331	117659 ± 343	93.031 ± 0.074	1.004 ± 0.010
0.5-0.6	810 ± 34	879 ± 37	92.176 ± 1.475	106827 ± 327	115559 ± 340	92.444 ± 0.078	1.003 ± 0.016
0.6-0.7	840 ± 33	919 ± 39	91.423 ± 2.057	102923 ± 321	112467 ± 335	91.514 ± 0.083	1.001 ± 0.023
0.7-0.8	703 ± 34	785 ± 37	89.511 ± 1.902	97006 ± 311	108271 ± 329	89.596 ± 0.093	1.001 ± 0.021
0.8-0.9	634 ± 30	791 ± 39	80.170 ± 2.628	81298 ± 285	101158 ± 318	80.367 ± 0.125	1.002 ± 0.033
0.9-1.0	114 ± 11	195 ± 22	58.685 ± 6.126	17954 ± 134	67066 ± 259	26.771 ± 0.171	0.456 ± 0.048

Particle identification efficiency

- The signal number and PID efficiency on the transverse momentum distribution of for PID efficiency of recoil proton.

p_t(GeV)	n_p(data)	N_p(data)	ϵ_{PID}(data) [%]	n_p(MC)	N_p(MC)	ϵ_{PID}(MC) [%]	1-Δ_{PID}
0.1-0.2	524 ± 28	561 ± 30	93.474 ± 1.846	65416 ± 256	69748 ± 264	93.789 ± 0.091	1.003 ± 0.020
0.2-0.3	3128 ± 56	3236 ± 71	96.668 ± 1.287	337257 ± 581	347742 ± 590	96.985 ± 0.029	1.003 ± 0.013
0.3-0.4	4156 ± 71	4212 ± 74	98.666 ± 0.406	421716 ± 649	426823 ± 653	98.803 ± 0.017	1.001 ± 0.004
0.4-0.5	3757 ± 69	3764 ± 69	99.807 ± 0.223	392377 ± 626	393514 ± 627	99.711 ± 0.009	0.999 ± 0.002
0.5-0.6	3040 ± 63	3050 ± 63	99.690 ± 0.093	318741 ± 565	319303 ± 565	99.824 ± 0.007	1.001 ± 0.001
0.6-0.7	1909 ± 52	1915 ± 51	99.673 ± 0.680	224333 ± 474	224704 ± 474	99.835 ± 0.009	1.002 ± 0.007
0.7-0.8	1022 ± 36	1024 ± 38	99.780 ± 1.094	133166 ± 365	133349 ± 365	99.863 ± 0.010	1.001 ± 0.011
0.8-0.9	349 ± 22	349 ± 25	99.900 ± 3.584	58549 ± 242	58628 ± 242	99.865 ± 0.015	1.000 ± 0.036

- The signal number and PID efficiency on the transverse momentum distribution of for PID efficiency of recoil anti-proton.

p_t(GeV)	$n_{\bar{p}}$(data)	$N_{\bar{p}}$(data)	ϵ_{PID}(data) [%]	$n_{\bar{p}}$(MC)	$N_{\bar{p}}$(MC)	ϵ_{PID}(MC) [%]	1-Δ_{PID}
0.1-0.2	548 ± 30	625 ± 31	87.639 ± 1.287	53824 ± 232	61110 ± 247	88.077 ± 0.131	1.005 ± 0.015
0.2-0.3	3202 ± 64	3321 ± 68	96.415 ± 0.686	327748 ± 572	337140 ± 581	97.214 ± 0.028	1.008 ± 0.007
0.3-0.4	4076 ± 76	4131 ± 74	98.656 ± 0.425	423634 ± 651	428954 ± 655	98.760 ± 0.017	1.001 ± 0.004
0.4-0.5	3704 ± 61	3728 ± 70	99.344 ± 0.940	396319 ± 630	398353 ± 631	99.489 ± 0.011	1.001 ± 0.009
0.5-0.6	3112 ± 65	3125 ± 71	99.562 ± 0.915	323821 ± 569	324951 ± 570	99.652 ± 0.010	1.001 ± 0.009
0.6-0.7	1897 ± 52	1904 ± 52	99.625 ± 0.488	230228 ± 480	230931 ± 481	99.696 ± 0.011	1.001 ± 0.005
0.7-0.8	1034 ± 40	1037 ± 40	99.682 ± 0.412	137611 ± 371	137982 ± 371	99.731 ± 0.014	1.000 ± 0.004
0.8-0.9	363 ± 24	363 ± 25	99.939 ± 2.048	59745 ± 244	59887 ± 245	99.763 ± 0.020	0.998 ± 0.020

Particle identification efficiency

- The signal number and PID efficiency on the angular distribution of for PID efficiency of recoil proton.

$\cos\theta_p$	n_p(data)	N_p(data)	ϵ_{PID}(data) [%]	n_p(MC)	N_p(MC)	ϵ_{PID}(MC) [%]	1-Δ_{PID}
-1.0--0.9	164 ± 13	171 ± 15	96.001 ± 4.296	17123 ± 131	17874 ± 134	95.798 ± 0.150	0.998 ± 0.045
-0.9--0.8	715 ± 36	727 ± 32	98.362 ± 2.170	84151 ± 290	85281 ± 292	98.675 ± 0.039	1.003 ± 0.022
-0.8--0.7	948 ± 36	957 ± 36	99.115 ± 0.305	98560 ± 314	99361 ± 315	99.194 ± 0.028	1.001 ± 0.003
-0.7--0.6	960 ± 33	968 ± 35	99.120 ± 1.188	104203 ± 323	105255 ± 324	99.001 ± 0.031	0.999 ± 0.012
-0.6--0.5	1015 ± 36	1021 ± 36	99.379 ± 0.335	108757 ± 330	109872 ± 331	98.985 ± 0.030	0.996 ± 0.003
-0.5--0.4	990 ± 36	993 ± 36	99.658 ± 0.334	111681 ± 334	112633 ± 336	99.155 ± 0.027	0.995 ± 0.003
-0.4--0.3	961 ± 31	971 ± 38	98.949 ± 2.319	113404 ± 337	114431 ± 338	99.103 ± 0.028	1.002 ± 0.023
-0.3--0.2	969 ± 40	978 ± 38	99.089 ± 1.498	114289 ± 338	115313 ± 340	99.112 ± 0.028	1.000 ± 0.015
-0.2--0.1	911 ± 34	929 ± 34	98.128 ± 0.815	115221 ± 339	116563 ± 341	98.849 ± 0.031	1.007 ± 0.008
-0.1-0.0	1049 ± 35	1071 ± 40	97.929 ± 1.726	114931 ± 339	117044 ± 342	98.195 ± 0.039	1.003 ± 0.018
0.0-0.1	1018 ± 36	1042 ± 39	97.717 ± 1.402	114913 ± 339	117120 ± 342	98.116 ± 0.040	1.004 ± 0.014
0.1-0.2	1068 ± 35	1088 ± 37	98.172 ± 1.129	115085 ± 339	116470 ± 341	98.811 ± 0.032	1.007 ± 0.012
0.2-0.3	1021 ± 37	1031 ± 36	99.022 ± 0.691	114415 ± 338	115355 ± 340	99.185 ± 0.026	1.002 ± 0.007
0.3-0.4	1078 ± 39	1087 ± 37	99.193 ± 0.953	113967 ± 338	114991 ± 339	99.109 ± 0.028	0.999 ± 0.010
0.4-0.5	1062 ± 36	1072 ± 37	99.118 ± 0.484	111522 ± 334	112483 ± 335	99.146 ± 0.027	1.000 ± 0.005
0.5-0.6	1024 ± 35	1034 ± 36	99.066 ± 1.049	108492 ± 329	109655 ± 331	98.939 ± 0.031	0.999 ± 0.011
0.6-0.7	1024 ± 42	1029 ± 36	99.452 ± 2.018	104838 ± 324	105913 ± 325	98.985 ± 0.031	0.995 ± 0.020
0.7-0.8	1008 ± 32	1014 ± 41	99.425 ± 2.481	98351 ± 314	99149 ± 315	99.195 ± 0.028	0.998 ± 0.025
0.8-0.9	893 ± 30	908 ± 39	98.374 ± 2.685	86005 ± 293	87010 ± 295	98.845 ± 0.036	1.005 ± 0.027
0.9-1.0	209 ± 14	214 ± 21	97.700 ± 6.687	17582 ± 133	18100 ± 135	97.138 ± 0.124	0.994 ± 0.068

Particle identification efficiency

- The signal number and PID efficiency on the angular distribution of for PID efficiency of recoil anti-proton.

$\cos\theta_{\bar{p}}$	$n_{\bar{p}}$(data)	$N_{\bar{p}}$(data)	ϵ_{PID}(data) [%]	$n_{\bar{p}}$(MC)	$N_{\bar{p}}$(MC)	ϵ_{PID}(MC) [%]	1-Δ_{PID}
−1.0-−0.9	219 ± 15	234 ± 18	93.550 ± 4.015	15419 ± 124	16215 ± 127	95.091 ± 0.170	1.016 ± 0.044
−0.9-−0.8	853 ± 34	873 ± 39	97.638 ± 2.039	81047 ± 285	82927 ± 288	97.733 ± 0.052	1.001 ± 0.021
−0.8-−0.7	1005 ± 32	1016 ± 37	98.945 ± 1.850	98662 ± 314	100114 ± 316	98.550 ± 0.038	0.996 ± 0.019
−0.7-−0.6	1010 ± 38	1024 ± 39	98.618 ± 0.939	104973 ± 324	106332 ± 326	98.722 ± 0.034	1.001 ± 0.010
−0.6-−0.5	982 ± 37	990 ± 42	99.125 ± 2.030	109352 ± 331	110685 ± 333	98.796 ± 0.033	0.997 ± 0.020
−0.5-−0.4	1031 ± 34	1040 ± 37	99.150 ± 1.515	112575 ± 336	113798 ± 337	98.925 ± 0.031	0.998 ± 0.015
−0.4-−0.3	1057 ± 39	1072 ± 38	98.610 ± 0.419	114537 ± 338	115846 ± 340	98.870 ± 0.031	1.003 ± 0.004
−0.3-−0.2	1062 ± 38	1074 ± 39	98.828 ± 1.011	115801 ± 340	116983 ± 342	98.990 ± 0.029	1.002 ± 0.010
−0.2-−0.1	982 ± 31	998 ± 37	98.348 ± 2.028	116039 ± 341	117519 ± 343	98.741 ± 0.033	1.004 ± 0.021
−0.1-0.0	1050 ± 35	1065 ± 40	98.605 ± 1.742	116577 ± 341	118299 ± 344	98.544 ± 0.035	0.999 ± 0.018
0.0-0.1	975 ± 40	989 ± 39	98.528 ± 0.718	116647 ± 342	118389 ± 344	98.529 ± 0.035	1.000 ± 0.007
0.1-0.2	1037 ± 32	1052 ± 40	98.529 ± 2.191	116430 ± 341	117956 ± 343	98.706 ± 0.033	1.002 ± 0.022
0.2-0.3	1027 ± 38	1039 ± 39	98.779 ± 0.831	115645 ± 340	116804 ± 342	99.008 ± 0.029	1.002 ± 0.008
0.3-0.4	937 ± 35	952 ± 36	98.416 ± 0.659	114189 ± 338	115446 ± 340	98.911 ± 0.031	1.005 ± 0.007
0.4-0.5	1039 ± 32	1057 ± 37	98.330 ± 1.687	111995 ± 335	113295 ± 337	98.853 ± 0.032	1.005 ± 0.017
0.5-0.6	954 ± 36	963 ± 38	99.092 ± 1.383	109054 ± 330	110373 ± 332	98.805 ± 0.033	0.997 ± 0.014
0.6-0.7	1015 ± 32	1034 ± 40	98.135 ± 2.344	104817 ± 324	106215 ± 326	98.684 ± 0.035	1.006 ± 0.024
0.7-0.8	833 ± 34	846 ± 38	98.470 ± 1.732	98607 ± 314	100075 ± 316	98.533 ± 0.038	1.001 ± 0.018
0.8-0.9	798 ± 30	820 ± 36	97.218 ± 2.322	81402 ± 285	83404 ± 289	97.600 ± 0.053	1.004 ± 0.024
0.9-1.0	131 ± 11	154 ± 16	84.913 ± 6.161	15144 ± 123	16139 ± 127	93.835 ± 0.189	1.105 ± 0.080