Measurements of baryon form factor at BESIII

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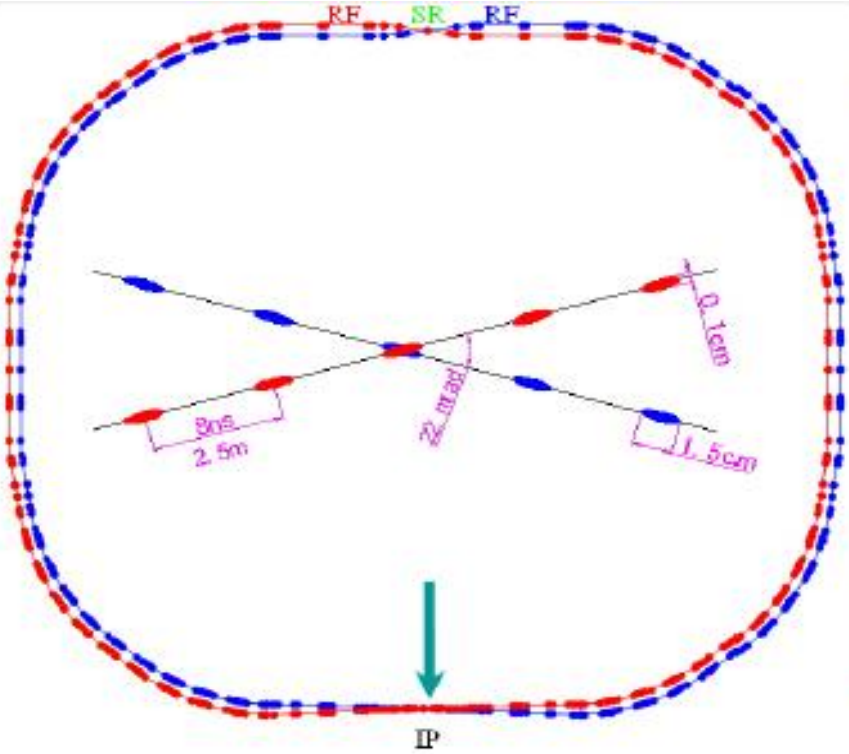
Outline

- BEPCII &BESIII experiment
- $e^+e^- \to p\bar{p}$ analysis
- $e^+e^- \to \Lambda\bar{\Lambda}$ analysis
- Prospects & Summary

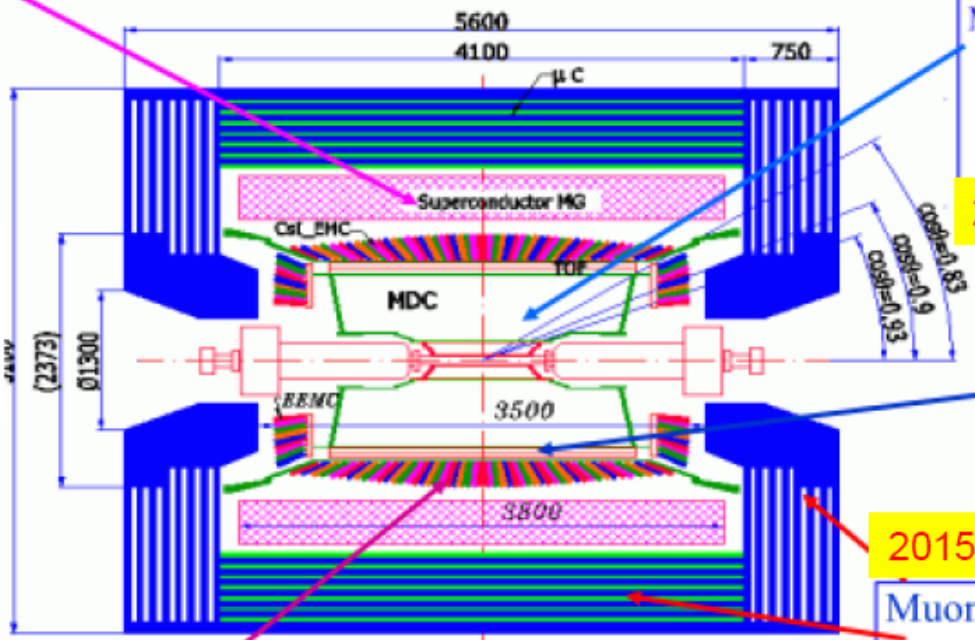
Double Storage Rings of BEPCII



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 Detector

Solenoid Magnet: 1 T Super conducting



MDC: small cell & He gas
σ_{xy}=130 μm
$\delta p/p$ = 0.5% @1GeV
dE/dx=6%

2017-18: Inner upgrade

Ref:
NIM A614, 345 (2010)

TOF:
σ_T = 90 ps Barrel
110 ps Endcap

2015 ETOF upgrade: 70ps

Muon ID: 8~9 layer RPC
$\sigma_{R\Phi}$=1.4 cm~1.7 cm

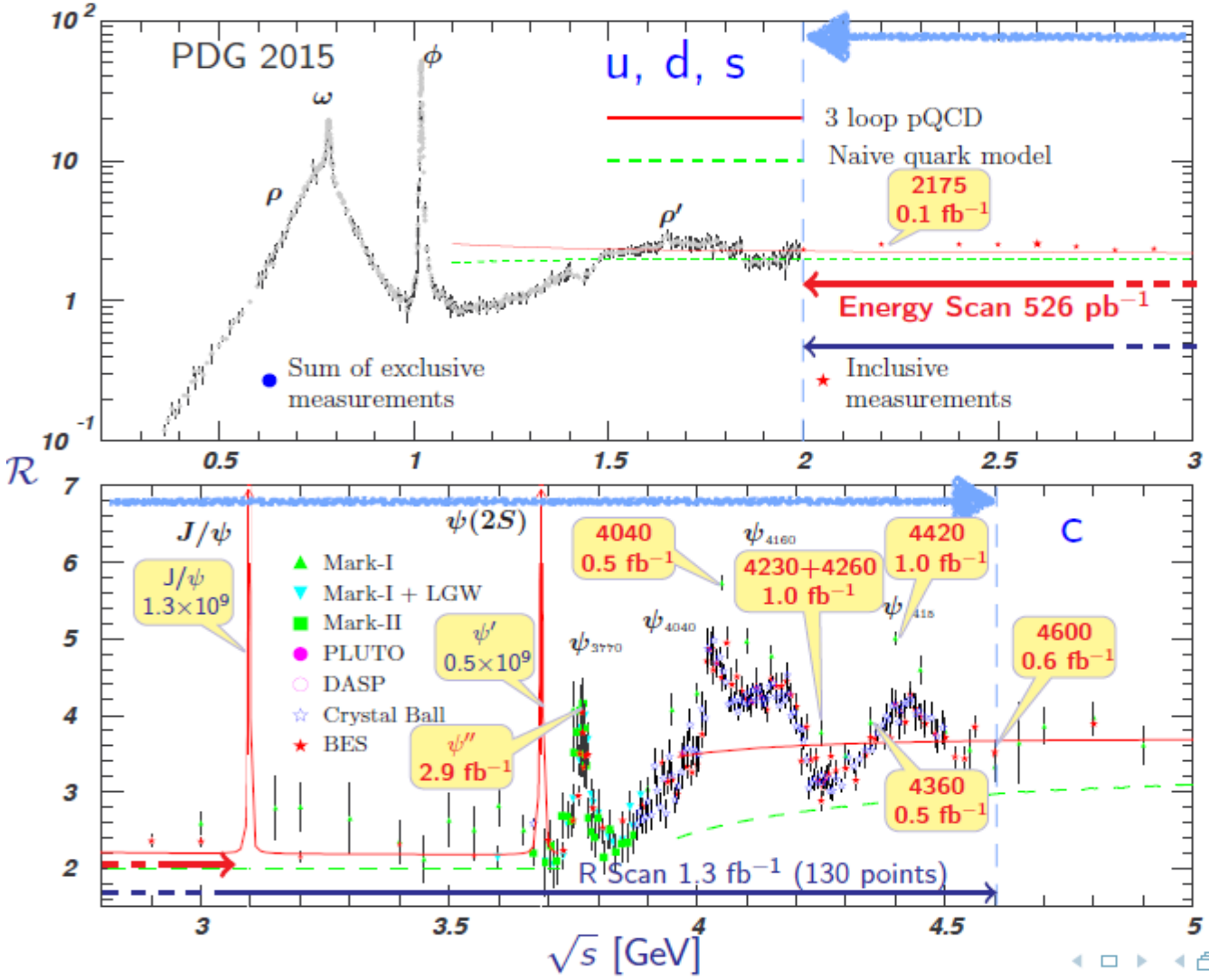
EMCAL: CsI crystal
ΔE/E = 2.5% @1 GeV
$\sigma_{\phi,z}$ = 0.5~0.7 cm/√E

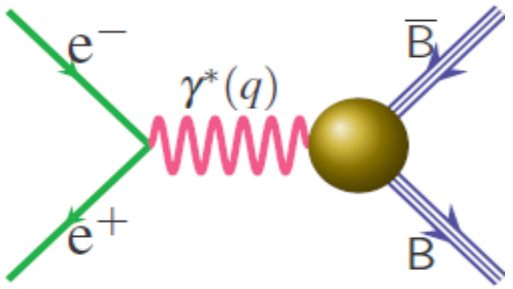
Data Acquisition:
Event rate = 3 kHz
Throughput ~ 50 MB/s

Trigger: Tracks & Showers
Pipelined; Latency = 6.4 μs

Clean environment and high luminosity at BESIII are helpful for indirect probe of new physics

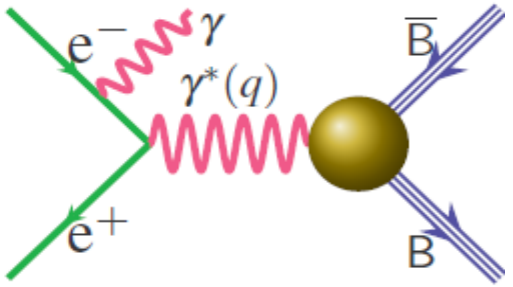
BESIII data samples



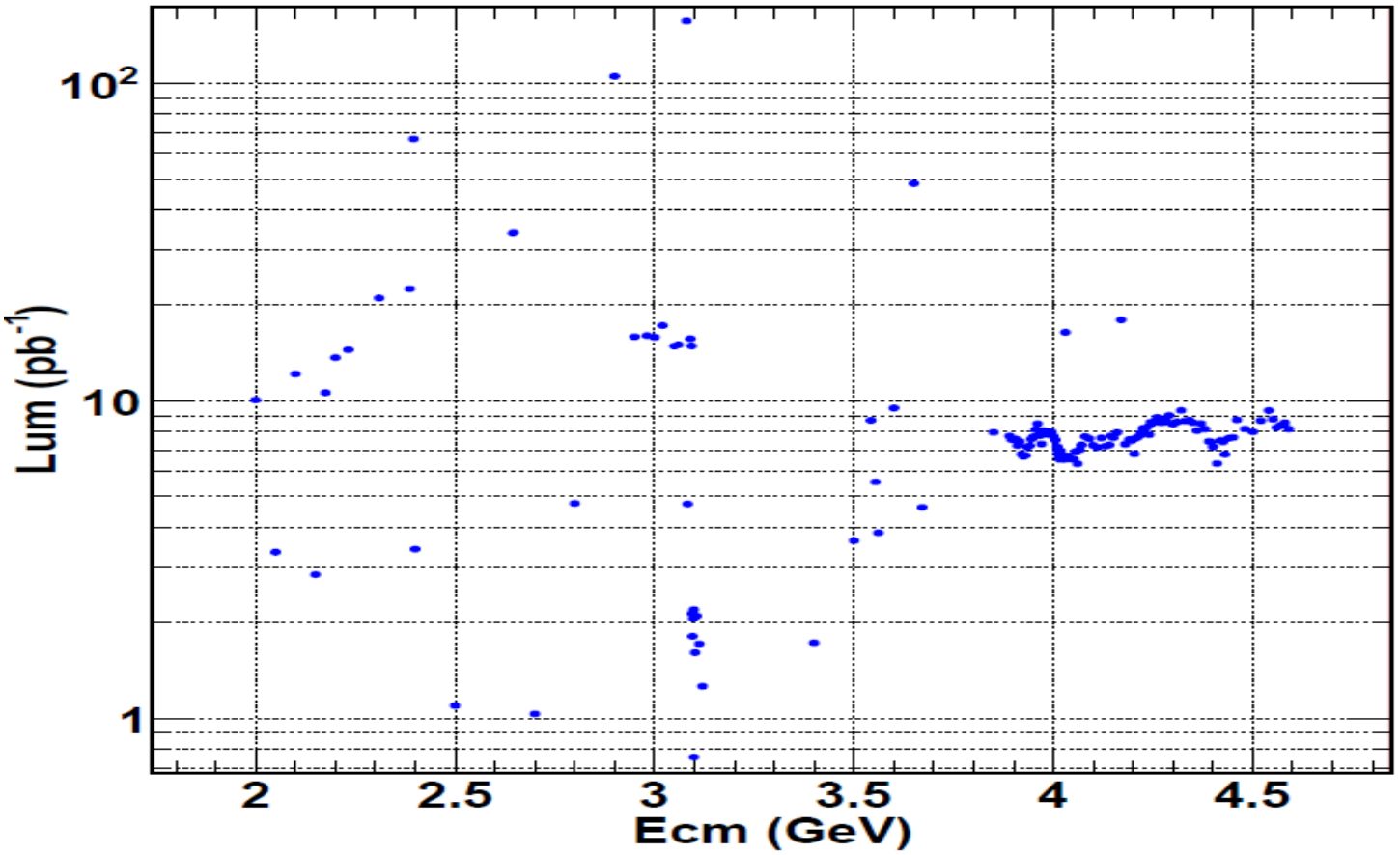


Baryon FFs
from energy scan data
by $e^+e^- \to B\bar{B}$

Baryon FFs from data
by $e^+e^- \to B\bar{B}\gamma_{ISR}$
($\mathcal{L}_{int}(\geq \psi'')$: 7.4 fb^{-1})



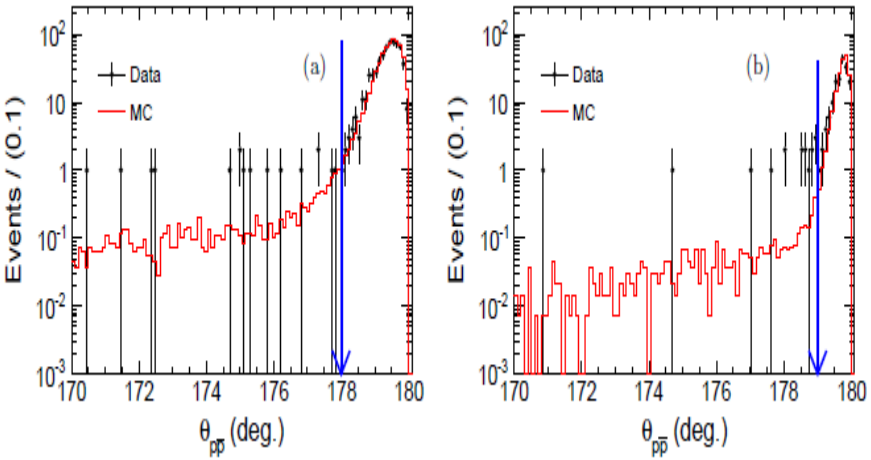
BESIII data samples
τ-QCD scan data
($\sqrt{s}$ =2.00~4.59 GeV)

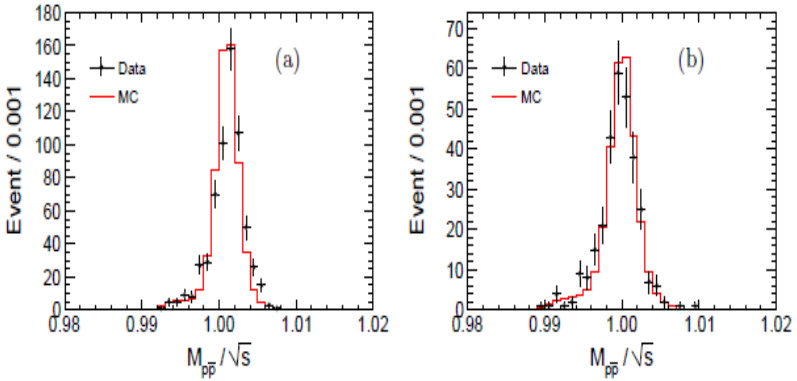


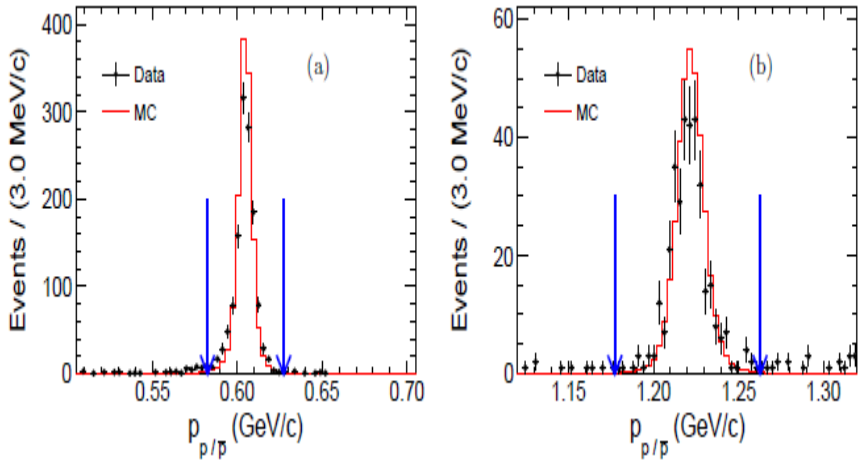
Measurement of nucleon form factor by studying $e^+e^- \rightarrow p\bar{p}$

Event selection

1. Two charged tracks from the vertex
2. $|\cos\theta|<0.93$ (0.80)
3. PID (tof & dE/dx)
4. $\theta_{p\bar{p}}<178^0(179^0)$
5. $|p_{mea}-p_{exp}|<5\sigma_p$







Background analysis

	E_{cm} = 2.2324			($\mathcal{L}$=2.634 pb^{-1})
Bkg	N^{MC}_{gen}	N^{MC}_{sur}	$\sigma(nb)$	$N^{data}_{uplimit}$(90% CL)
e^+e^-	9.6×10^6	0	1434.01	< 0.96
$\mu^+\mu^-$	7.0×10^5	0	17.41	< 0.16
$\gamma\gamma$	1.9×10^6	0	70.44	< 0.24
$\pi^+\pi^-$	1.0×10^5	0	0.173	< 0.01
K^+K^-	1.0×10^5	0	0.138	< 0.008
$p\bar{p}\pi^0$	1.0×10^5	0	< 0.1	< 0.006
$p\bar{p}\pi^0\pi^0$	1.0×10^5	0	< 0.1	< 0.006
$\Lambda\bar{\Lambda}$	1.0×10^5	0	0.4	< 0.02

	E_{cm} = 3.08			($\mathcal{L}$=30.73 pb^{-1})
Bkg	N^{MC}_{gen}	N^{MC}_{sur}	$\sigma(nb)$	$N^{data}_{uplimit}$(90% CL)
e^+e^-	3.99×10^7	1	756.86	< 2.54
$\mu^+\mu^-$	1.50×10^6	0	8.45	< 0.42
$\gamma\gamma$	4.5×10^6	0	37.05	< 0.62
$\pi^+\pi^-$	1.0×10^5	0	< 0.111	< 0.02
K^+K^-	1.0×10^5	0	0.0933	< 0.02
$p\bar{p}\pi^0$	1.0×10^5	0	< 0.1	< 0.07
$p\bar{p}\pi^0\pi^0$	1.0×10^5	0	< 0.1	< 0.07
$\Lambda^0\bar{\Lambda}^0$	1.0×10^5	0	0.002	0.001

	E_{cm} = 3.65			($\mathcal{L}$=48.823 pb^{-1})
Bkg	N^{MC}_{gen}	N^{MC}_{sur}	$\sigma(nb)$	N^{data}_{mix} (90% CL)
e^+e^-	4.44×10^7	1	537.46	< 2.58
$\mu^+\mu^-$	1.5×10^6	0	6.50	< 0.52
$\gamma\gamma$	5.5×10^6	0	26.33	< 0.57
$\pi^+\pi^-$	1.0×10^5	0	0.044	< 0.01
K^+K^-	1.0×10^5	0	0.0400	< 0.01
$p\bar{p}\pi^0$	1.0×10^5	0	< 0.1	< 0.1
$p\bar{p}\pi^0\pi^0$	1.0×10^5	0	< 0.1	< 0.1
$\Lambda^0\bar{\Lambda}^0$	1.0×10^5	0	0.002	< 0.002
$\tau\tau$	1.0×10^6	0	2.0	< 0.1

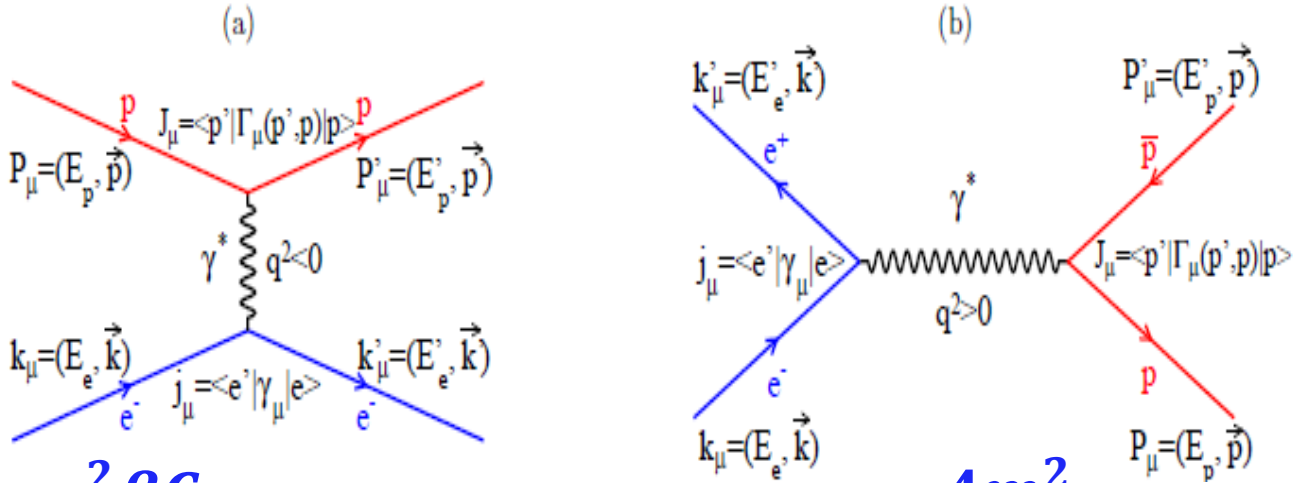
E_{cm} (GeV)	N^{data}_{pro}	N^{data}_{sur}
2.40	9412203	0
3.40	13191714	0

Separated beam data

Background events are almost negligible

Strategy of analysis

Energy scan method



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

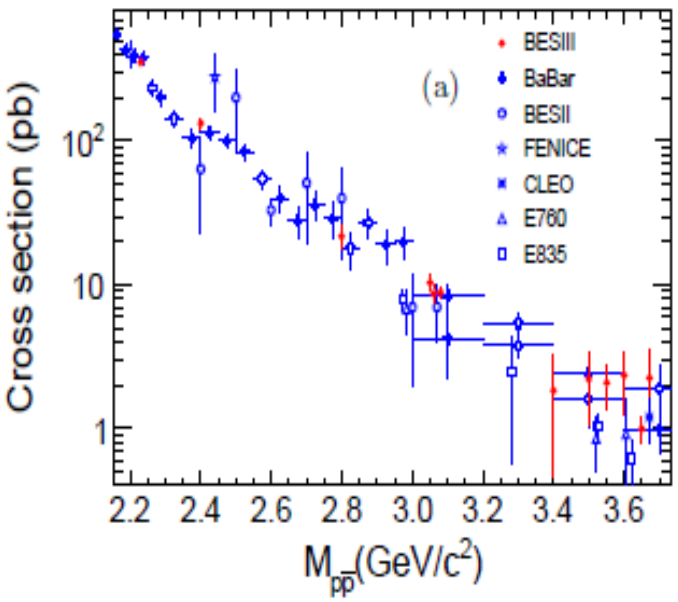
$$|G|=\sqrt{\frac{\sigma_{Born}}{86.83\cdot\frac{\beta}{s}\left(1+\frac{2m_p^2}{s}\right)}}$$

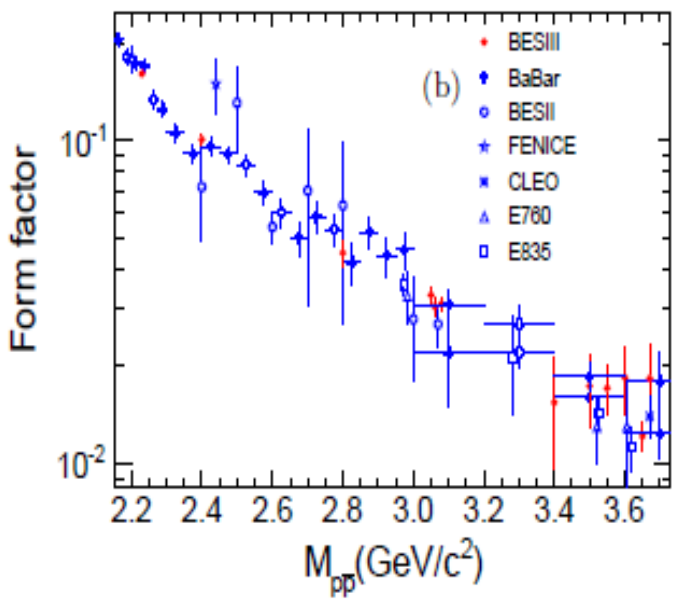
$$\sigma_{Born}=\frac{N_{obs}-N_{bkg}}{\mathcal{L}\cdot\varepsilon\cdot(1+\delta)}$$

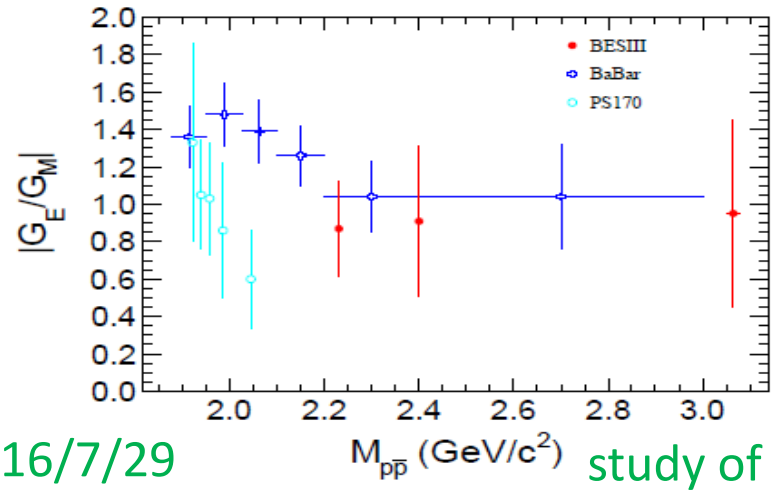
Result of analysis

$\sqrt{s}$ (MeV)	N_{obs}	N_{bkg}	ε' (%)	L (pb^{-1})	σ_{Born} (pb)	$\lvert G\rvert$ ($\times 10^{-2}$)
2232.4	614 ± 25	1	66.00	2.63	$353.0 \pm 14.3 \pm 15.5$	$16.10 \pm 0.32 \pm 0.35$
2400.0	297 ± 17	1	65.79	3.42	$132.7 \pm 7.7 \pm 8.1$	$10.07 \pm 0.29 \pm 0.31$
2800.0	53 ± 7	1	65.08	3.75	$21.3 \pm 3.0 \pm 2.8$	$4.45 \pm 0.31 \pm 0.29$
3050.0	91 ± 10	2	59.11	14.90	$10.1 \pm 1.1 \pm 0.6$	$3.29 \pm 0.17 \pm 0.09$
3060.0	78 ± 9	2	59.21	15.06	$8.5 \pm 1.0 \pm 0.6$	$3.03 \pm 0.17 \pm 0.10$
3080.0	162 ± 13	1	58.97	30.73	$8.9 \pm 0.7 \pm 0.5$	$3.11 \pm 0.12 \pm 0.08$
3400.0	2 ± 1	0	63.34	1.73	$1.8 \pm 1.3 \pm 0.4$	$1.54 \pm 0.55 \pm 0.18$
3500.0	5 ± 2	0	63.70	3.61	$2.2 \pm 1.0 \pm 0.6$	$1.73 \pm 0.39 \pm 0.22$
3550.7	24 ± 5	1	62.23	18.15	$2.0 \pm 0.4 \pm 0.6$	$1.67 \pm 0.17 \pm 0.23$
3600.2	14 ± 4	1	62.24	9.55	$2.2 \pm 0.6 \pm 0.9$	$1.78 \pm 0.25 \pm 0.35$
3650.0	36 ± 6	4	61.20	48.82	$1.1 \pm 0.2 \pm 0.1$	$1.26 \pm 0.11 \pm 0.07$
3671.0	6 ± 2	0	51.17	4.59	$2.2 \pm 0.9 \pm 0.8$	$1.84 \pm 0.37 \pm 0.33$

Comparison



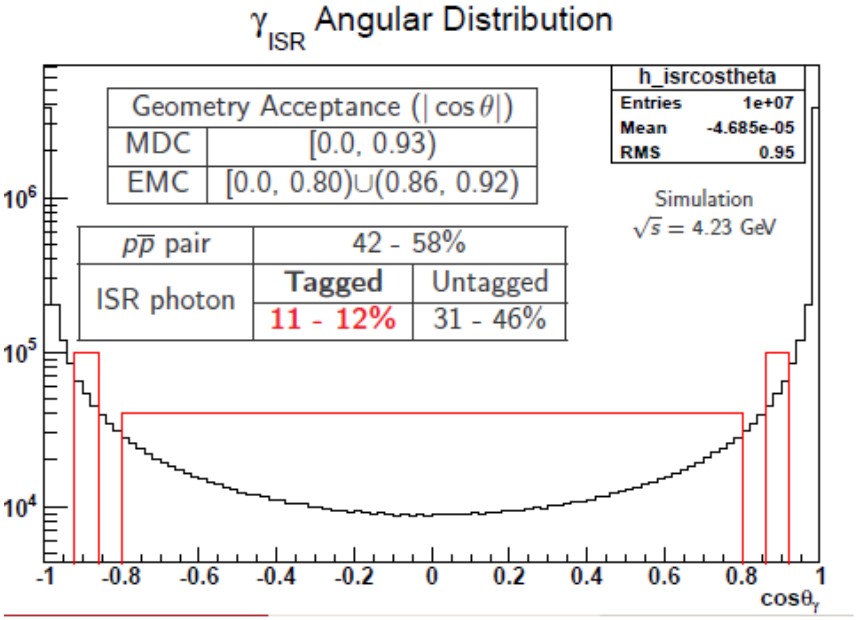


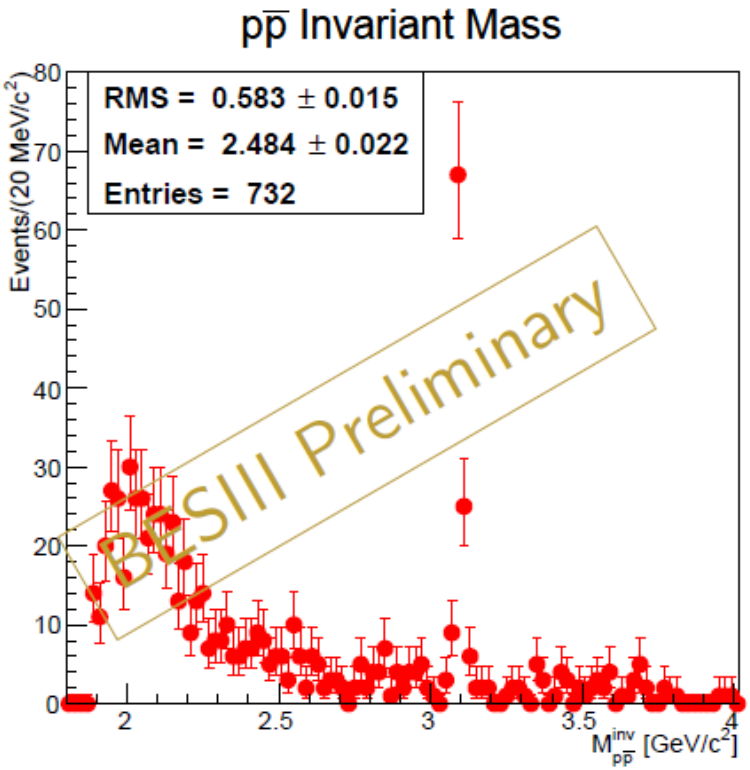


1. $|G_E|$ and $|G_M|$ extracted individually
2. Precision between 11% and 28%
3. Consistent with previous one at same q-range

ISR-Tagged Analysis for Proton

ISR method



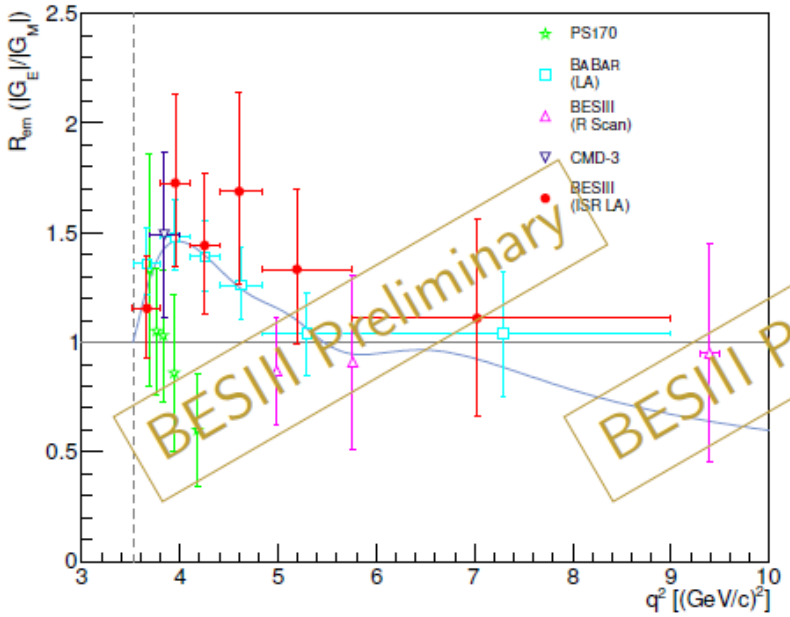


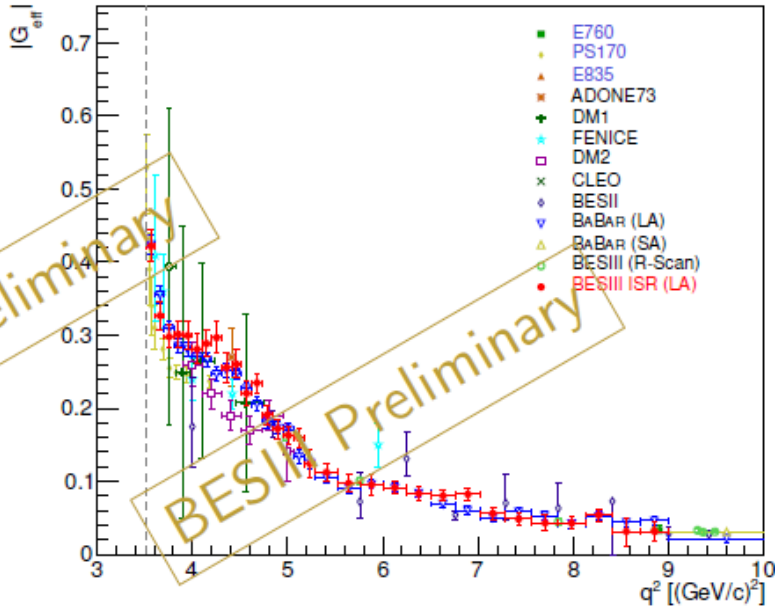
- 7 data samples ($\geq$ 3.773 GeV)
- Total luminosity 7.4 fb^{-1}
- Event selction:
  - Two charged tracks from vertex
  - One high energy shower in EMC
  - Kinematic constraints applied
- Background evaluation

Data at the energy 4.23 GeV

$p\bar{p}$ invariant mass spectrum from threshold

Results from ISR-Tagged Analysis





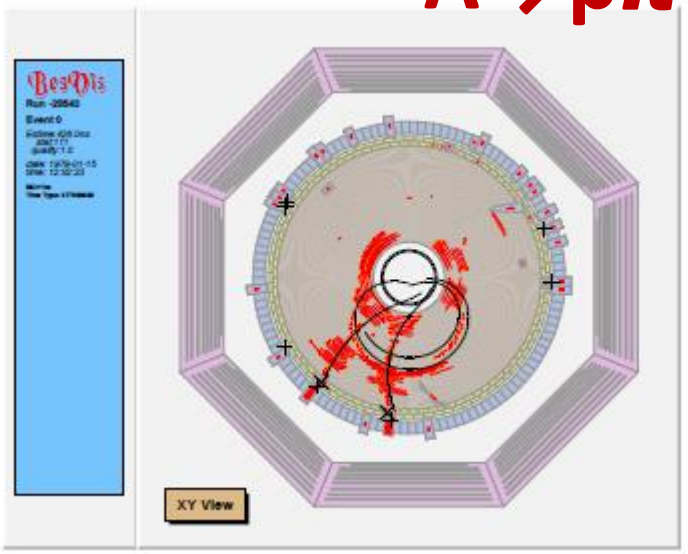
- Background subtraction and efficiency dividing
- Combine the seven data samples
- The proton FFs extracted between th. – 3.0 GeV
- Systematic uncertainty included

	$\frac{\delta R_{em}}{R_{em}}$	$\frac{\delta G_{eff}}{G_{eff}}$
stat.	16% - 34%	5% - 32%
syst.	5% - 22%	2% - 30%

LA: **L**arge polar **A**ngle of ISR photon
SA: **S**mall polar **A**ngle of ISR photon

Cross section measurement of $e^+e^- \to \Lambda\bar{\Lambda}$ with BESIII data at 2.2324, 2.40, 2.80 and 3.08 GeV

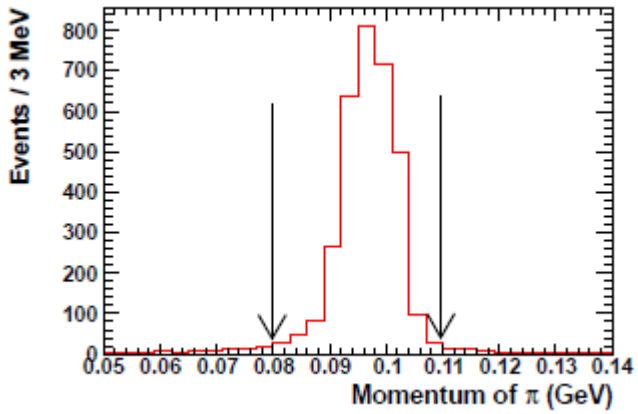
Event selection
$\bar{\Lambda}\to\bar{p}\pi^+$ (mode I)



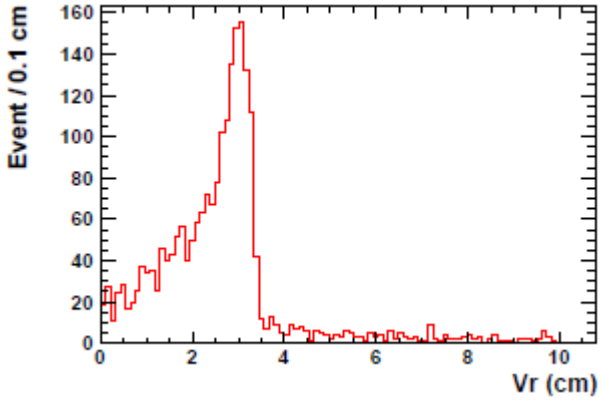
Signal Event display from MC simulation for $e^+e^-\to\Lambda\Lambda$

1. v_{xy}<1.0cm $|v_z|$<10cm
2. $|\cos\theta|$<0.93
3. Q=0， N_{track}=2
4. 0.08<P_π <0.11 GeV/c
5. PID （tof & dE/dx)

for π



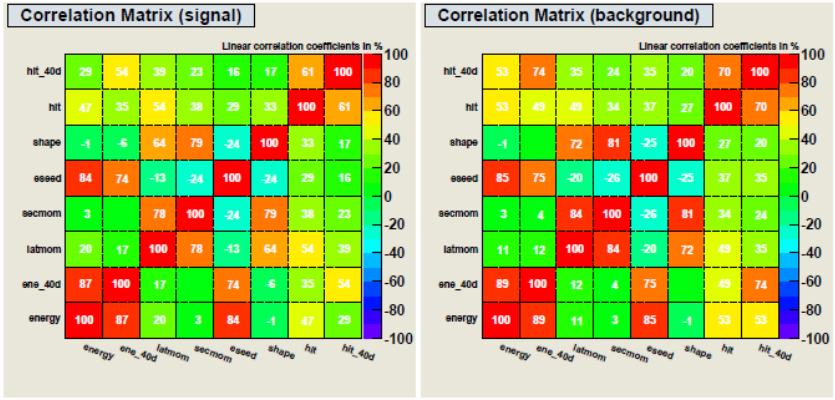
Vr<5cm for antiproton



Event selection
$\bar{\Lambda}\to\bar{n}\pi^0$ (mode II)

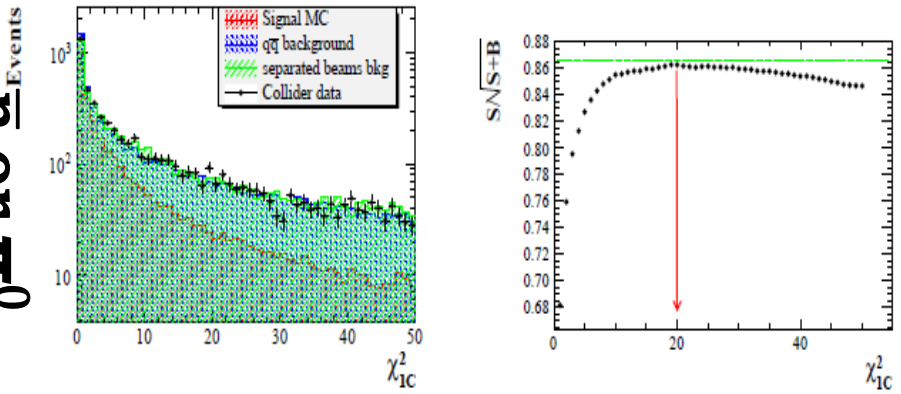
1. v_{xy}<1.0cm $|v_z|$<10cm
2. $|\cos\theta|$<0.93
3. Q=0， N_{track}=2
4. 0.08<P_π <0.11 GeV/c
5. PID （tof & dE/dx)

for π



1. Emc>25MeV (Barrel) & Emc>50MeV (Endcap)
2. $\theta_{\gamma ch}$>10, 3<N_{shower}<20
3. Multiple Variable Analysis select $\bar{n}$ from background
4. select π^0 requirement: 0<T<14 (50ns) ;
5. $|E_{\gamma1}-E_{\gamma2}|/P_{\pi0}$<0.95;$\chi^2_{1C}$ <20
6. $\theta_{\pi^0\bar{n}}$ >140^0

$\bar{n}$ or π^0



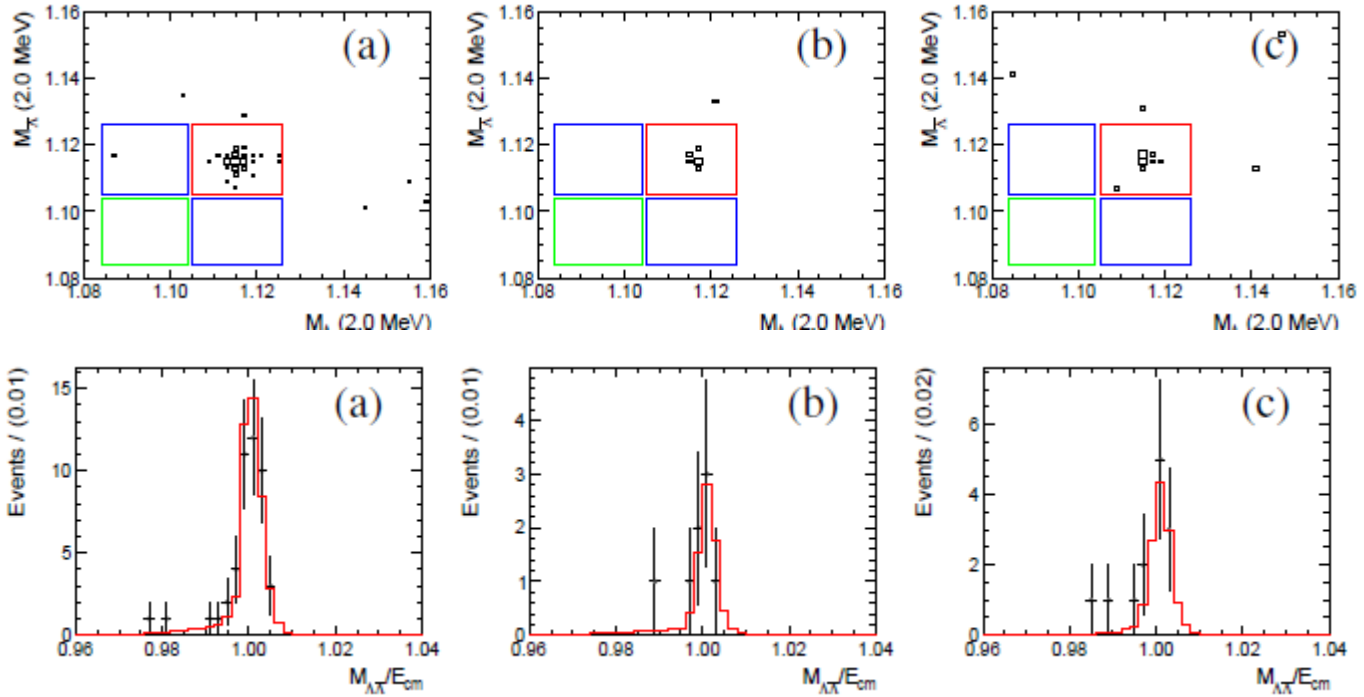
Background is negligible

Background analysis

Final states	Luminosity (pb^{-1})	Events generated	Events survived	Normalized number
e^+e^-	1.47	2.14M	2	3.6
$\mu^+\mu^-$	1.47	26.7k	1	1.8
$\gamma\gamma$	1.47	103k	0	0
e^+e^-X	1.47	24k	22	39.4
$q\bar{q}$	1.47	53.5k	339	606.7

2.2324

2.40 2.80 3.08

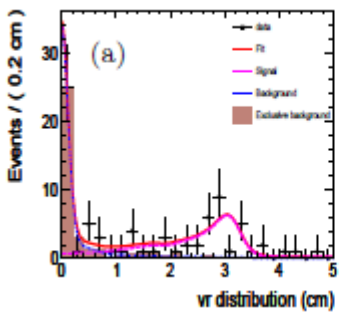


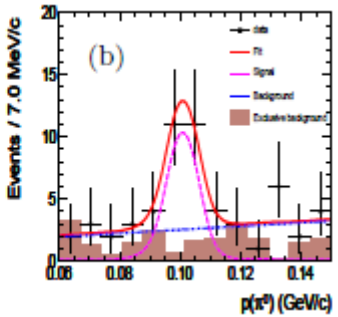
Strategy of analysis

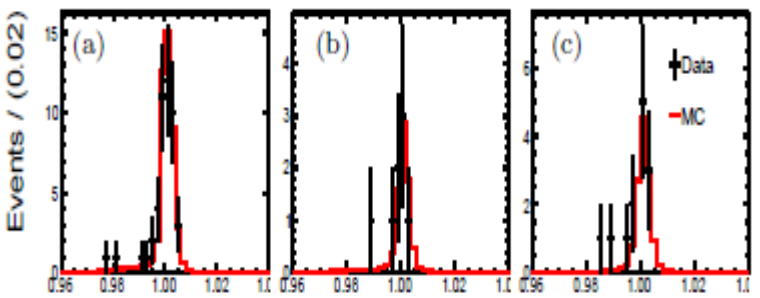
$$\sigma_{B\bar{B}}(\mathrm{m}) = \frac{4\pi\alpha^2 C\beta}{3m^2}\left[|G_M(m)|^2 + \frac{1}{2\tau}|G_E(m)|^2\right]$$

$$|G| = \sqrt{\frac{3m^2\sigma^B}{4\pi\alpha^2\beta(1+\frac{1}{2\tau})}} \qquad \beta = \sqrt{1-\frac{4m_B^2}{s}} \qquad \tau = \frac{m^2}{4m_B^2}$$

$$\sigma^{\mathrm{B}} = \frac{\mathrm{N_{obs}} - N_{bkg}}{\mathcal{L}\cdot\varepsilon\cdot(1+\delta)\cdot \mathrm{Br}(\Lambda\to \mathrm{p}\pi^-)\cdot \mathrm{Br}(\bar{\Lambda}\to\bar{p}\pi^+)}$$







Systematic uncertainty

Ecm=2.2324GeV

Table 7: Summary of the uncertainties.

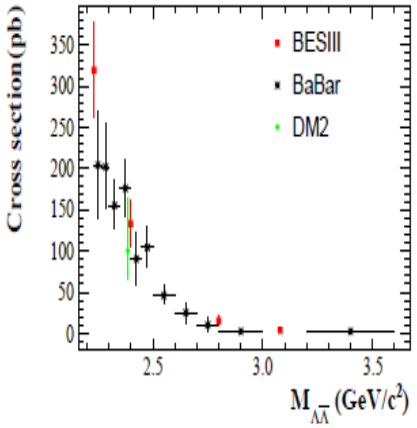
Systematic source	Uncertainty
$\bar{n}$ selection	2.2%
π^0 selection	2.1%
χ^2_{1C} cut	0.9%
MVA classifier cut	4.8%
Fitting range	3.9%
Background shape	4.6%
MC generator	3.2%
Energy spread	2.0%
Energy scale	3.9%
Trigger efficiency	1.0%
Luminosity	1.0%
sum	12%

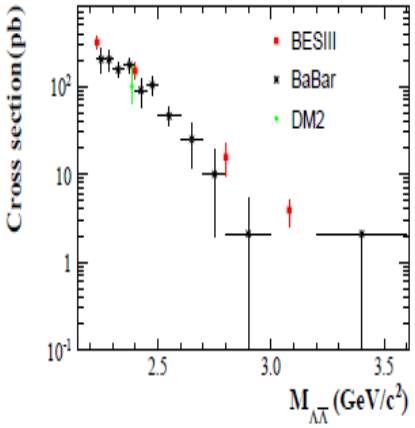
Ecm=2.40 2.80 3.08 GeV

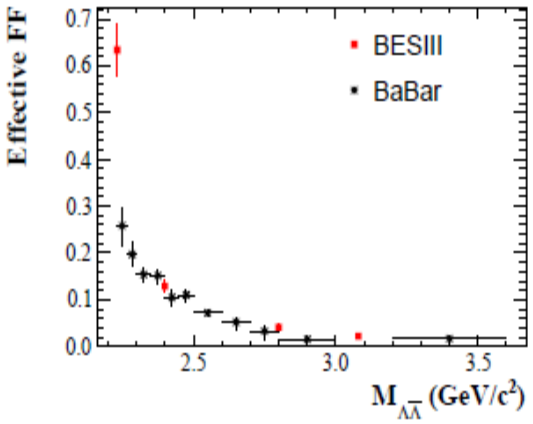
Source	2.40 GeV	2.80 GeV	3.08 GeV
Reconstruction of Λ	3.8	3.8	3.8
Reconstruction of $\bar{\Lambda}$	3.4	3.4	3.4
Mass window cut of Λ	2.5	2.5	2.5
Mass window cut of $\bar{\Lambda}$	3.0	3.0	3.0
Angular distribution	12.7	10.8	11.4
Input lineshape	2.2	4.0	2.9
Luminosity	1.0	1.0	1.0
Total	14	13	13

Results & comparison

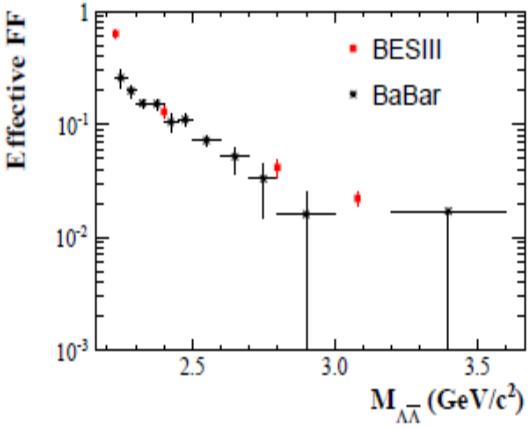
$\sqrt{s}$ GeV	Reconstruction	σ_{Born} (pb)	$\lvert G\rvert$ ($\times 10^{-2}$)
2.2324	$\Lambda \to p\pi^-, \bar{\Lambda} \to \bar{p}\pi^+$	$325 \pm 53 \pm 46$	
	$\bar{\Lambda} \to \bar{n}\pi^0$	$(3.0 \pm 1.0 \pm 0.4) \times 10^2$	
	combined	316 ± 61	63.0 ± 6.1
2.40		$133 \pm 20 \pm 19$	$12.93 \pm 0.97 \pm 0.92$
2.80		$15.3 \pm 5.4 \pm 2.0$	$4.16 \pm 0.73 \pm 0.27$
3.08		$3.9 \pm 1.1 \pm 0.5$	$2.21 \pm 0.31 \pm 0.14$







(a)



(b)

1.Preliminary results for Λ
2.Non-zero behavior at threshold
3.Precision improved by 10%

Prospects of the Baryon FFs at BESIII

- Proton FFs:
  - Energy scan between 2.0 – 3.08 GeV.
  - High precision $|G_M|$ and $|G_E|$ (R_{em}) extraction individually.
  - More data at high energy resonances for both ISR **tagged** and **untagged** analysis.
- Neutron FFs:
  - **Extract $|G_M|$ and $|G_E|$ (R_{em}) first time** from energy scan.
  - ISR-tagged analysis for neutron effective FF from threshold.
- Hyperon FFs:
  - Full determination of Λ FFs and polarization.
  - Other hyperon channels including Σ^0, $\Sigma^{\pm}$ and Ω.
  - Charmed hyperon Λ_c at threshold.

Summary & outlook

- BESIII is an excellent laboratory for the measurement of Form factor since both ISR and scan method can be performed
- 《Measurement of the proton form factor by studying $e^+e^-\to p\bar{p}$》 this paper has been published on Phys. Rev. D91, 112004 (2015)
- 《Observation of an enhancement cross section of $\Lambda\bar{\Lambda}$ production near threshold with BESIII》 the paper is on progress
- Many measurements of baryon form factors by the ISR technique or scan method will be performed in the near future

Thanks for your attention !

ありがとうございます