Hadron Form Factors in BESIII

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on behalf of **BESIII-Collaboration**

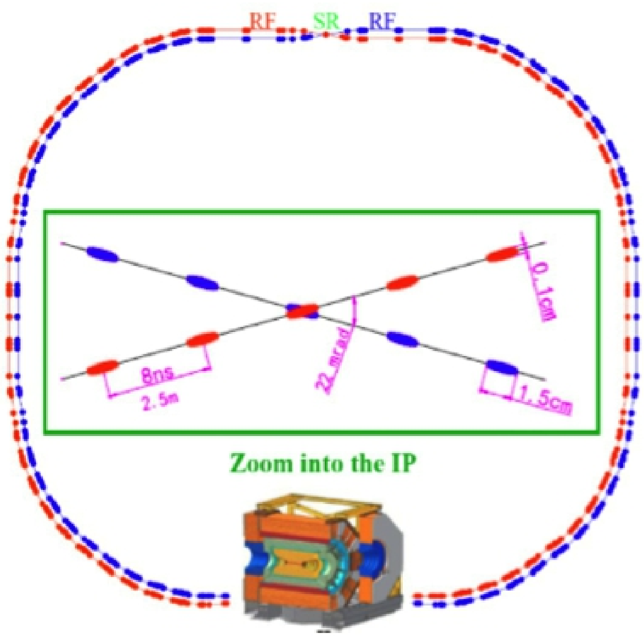
Outline:

- Experiment
- Motivation
- Nucleon Electromagnetic Form Factors
- Hyperon Electromagnetic Form Factors
- Pion Form Factor
- Summary

HADRON2015
September 13th – 18th, 2015, Newport News

BESIII@BEPCII

BESIII @ BEPCII



Double ring e+e- collider:

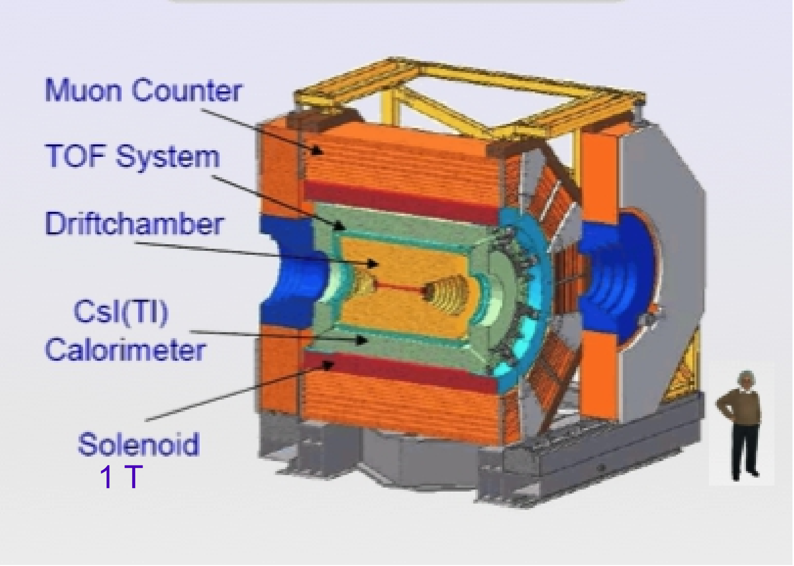
- Beam energy: 1.0 – 2.3 GeV
- Crossing angle: 22 mrad
- Design Luminosity at Ψ(3770): 10^{33} cm^{-2} s^{-1} ,85% achieved
- Optimum energy: 1.89 GeV
- Energy spread: $5.16 \cdot 10^{-4}$
- Number of bunches: 93
- Bunch length: 1.5 cm
- Total current: 0.91 A

MDC: **main drift chamber** (He 60% + propane 40%):
σ(p)/p < 0.5% for 1GeV tracks, σ(xy) = 130 μm
σ(dE/dx)/(dE/dx) < 6%

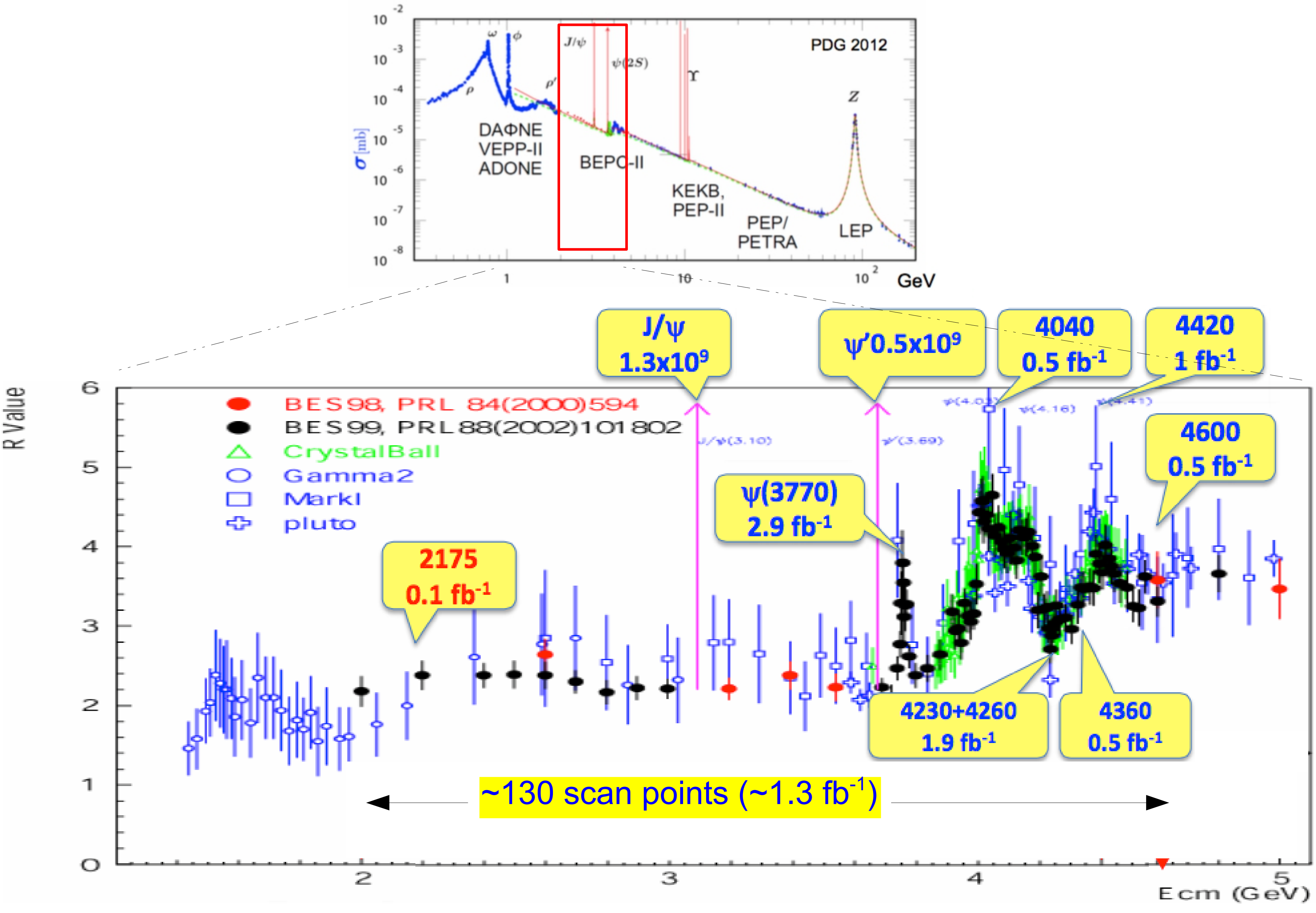
TOF: time of flight (two layers plastic scintillator): σ(t) ~ 90 ps

EMC: Cs I(Tl), barrel+2 end caps:
σ(E)/E < 2.5 %, σ(x) < 6mm for 1 GeV e-

MUC: time of flight (RPC): σ(xy) < 2 cm



BESIII Data Samples

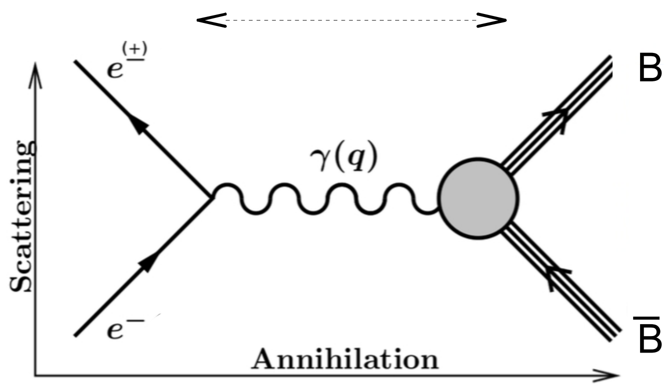


Motivation

Hadron Form Factors

- All **hadronic structure** and **strong interactions** in form factors but subject to QED corrections

  Hadronic vector current: (2s+1) form factors. For baryons 2 electromagnetic FFs:



B = p, n, Λ, Σ ...

Vector current. Dirac and Pauli FFs:

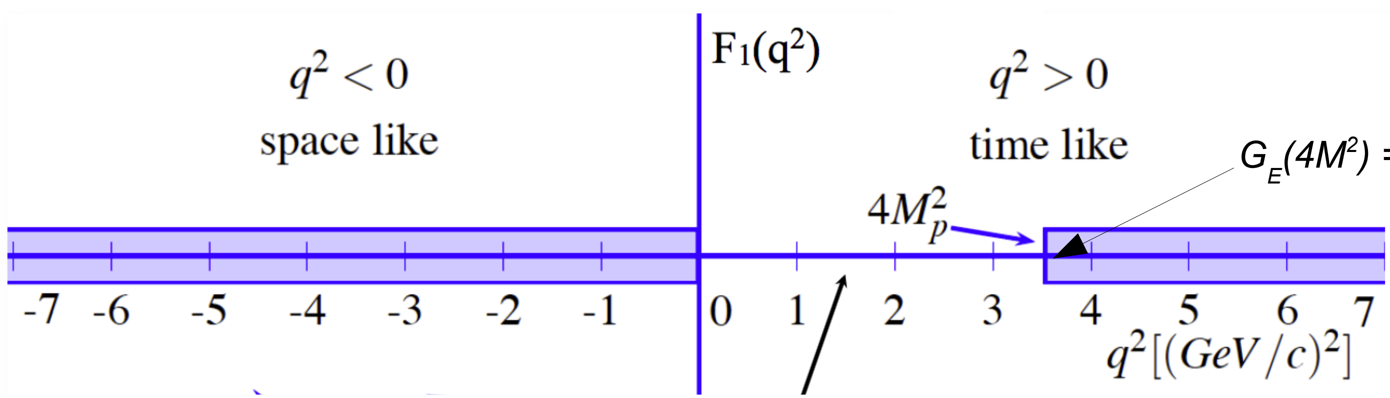
$$\Gamma^\mu = \gamma^\mu F_1(q^2) + \frac{i\sigma^{\mu\nu}q_\nu}{2M_B}F_2(q^2)$$

Sachs parametrization:

$$G_E(q^2) = F_1(q^2) + \frac{q^2}{4M_B}F_2(q^2)$$

$$G_M(q^2) = F_1(q^2) + F_2(q^2)$$

PQCD and analiticity: asymptotic behaviour



$G_E(4M^2) = G_M(4M^2)$

PQCD and analiticity: asymptotic behaviour

unphysical region

Form Factors real

cross section (Rosenbluth)
no single spin observables
double spin observables

connected by dispersion relations

Form Factors complex

cross section (angular Distr.)
single spin observables (P_y)
double spin observables

Hadron Form Factors

- **Fundamental properties of hadrons**

  Contain information on charge, magnetization distribution

  Connected to distribution, dynamics of quarks

  Crucial testing ground for models of hadron internal structure

  Necessary input for experiments probing hadronic structure, or trying to understand modification of hadronic structure in hadronic medium

- **Driving renewed activity on theory side:**

  Models trying to explain all four EM FFs of Nucleons

  Trying to explain data at both low and high q^2

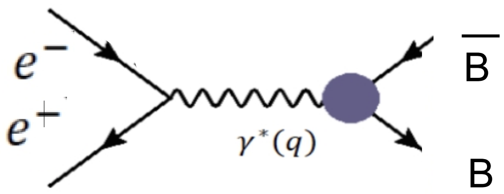
  Progress on QCD based calculations

  ...

Baryon EM FFs in BESIII

- BESIII @ BEPCII: e+e- -annihilation: access to **time-like form factors** from

Direct annihilation

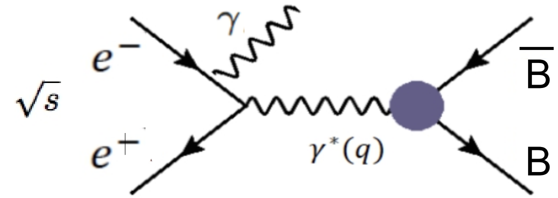


$$\sigma^{Born}_{B\bar{B}}(q^2) = \frac{4\pi\alpha^2\beta C}{3q^2}\left[|G_M(q^2)|^2 + \frac{1}{2\tau}|G_E(q^2)|\right]$$

Coulomb correction factor:

$$C = \frac{\pi\alpha}{\beta(1-exp(\pi\alpha/\beta))}$$ (if $q_B \neq 0$), $C = 1$ (if $q_B = 0$)

Initial State Radiation



B = p, n, Λ, Σ ...

$$\frac{d^2\sigma_{B\bar{B}\gamma}}{dx d\theta_\gamma} = W(s,x,\theta_\gamma)\sigma^{Born}_{B\bar{B}}(q^2)$$

$$W_{LO}(s,x,\theta_\gamma) = \frac{\alpha}{\pi x}\left(\frac{2-2x+x^2}{\sin^2\theta_\gamma} - \frac{x^2}{2}\right)$$

$$x = 1 - q^2/s = 2E_\gamma/\sqrt{s}$$

Effective form factor (assume $|G_E| = |G_M|$):

$$|G(q^2)| = \sqrt{\frac{\sigma^{Born}_{B\bar{B}}(q^2)}{(1+\frac{1}{2\tau})(\frac{4\pi\alpha^2\beta C}{3q^2})}}$$

Separation of $|G_E|$ and $|G_M|$ through angular analysis:

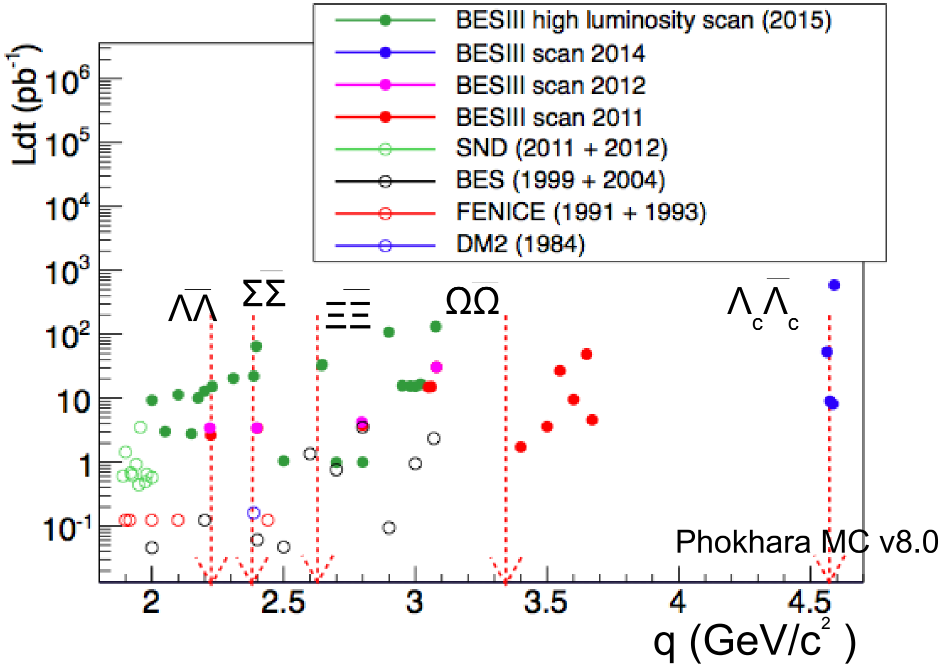
$$\frac{d\sigma^{Born}_{B\bar{B}}}{d\Omega_{CM}} = \frac{\alpha^2\beta C}{4q^2}\left[(1+\cos^2\theta^{CM}_B)|G_M|^2 + \frac{1}{\tau}|G_E|^2\sin^2\theta^{CM}_B\right]$$

with $\tau = \frac{q^2}{4M_B^2}, \beta = \sqrt{1-1/\tau}$

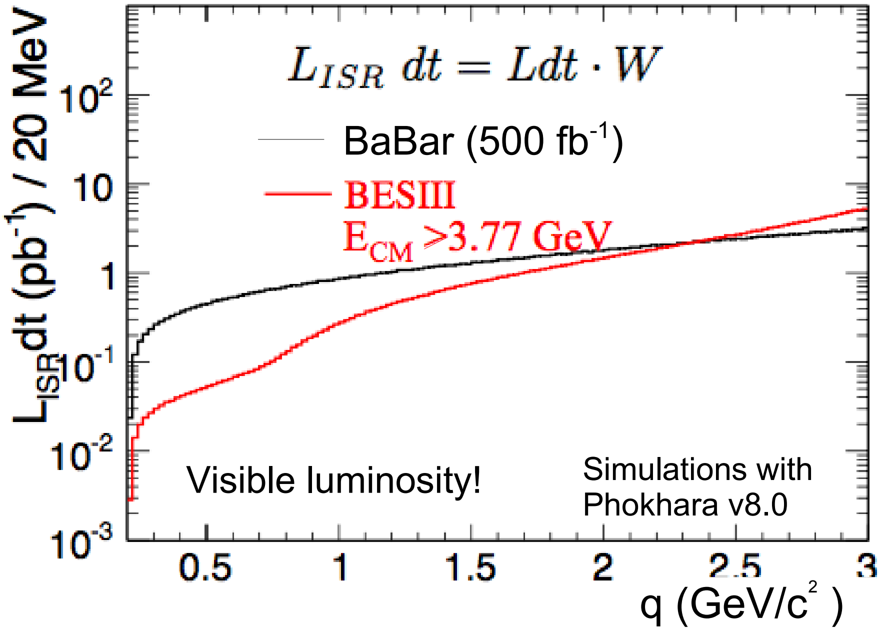
Data Samples for Hadron FFs

Data available for Hadron FFs measurements:

Direct annihilation



Initial State Radiation



Complementary approaches:

- High accuracy in q^2
- High geometrical acceptance for hadron pair (93%)
- Low background

- Continuous q^2-range available: $m^2_{th} < q^2 < s$
- Full angular distribution in hadronic center-of-mass
- Detection efficiency independent of q^2 and hadronic angular distribution
- Acceptance at threshold $\neq 0$

Nucleon EM FFs in BESIII

$e^+e^- \rightarrow p\bar{p}$ Phys. Rev. D91, 112004 (2015)

Analysis based on 157 pb^{-1} collected in 12 scan points between 2.22 – 3.71 GeV in 2011 and 2012

- Main features:
  - p and $\bar{p}$ from vertex, in time, back to back, $E_{p,\bar{p}} = E_{CM}/2$
  - Background negligible, ~4 GeV Bhabha subtracted
  - Efficiencies 60% (2.23 GeV) … 3% (~4 GeV)
  - Radiative corrections from ConExC (NLO in ISR)
  - Normalization to $e^+e^- \rightarrow e^+e^-$, $e^+e^- \rightarrow \gamma\gamma$ (Babayaga 3.5)

Born cross section

$$\sigma^{Born}_{p\bar{p}} = \frac{N_{p\bar{p}} - N_{bkg}}{L_{int} \cdot \epsilon_{geom} \cdot \epsilon_{detect} \cdot (1+\delta_{rad})}$$

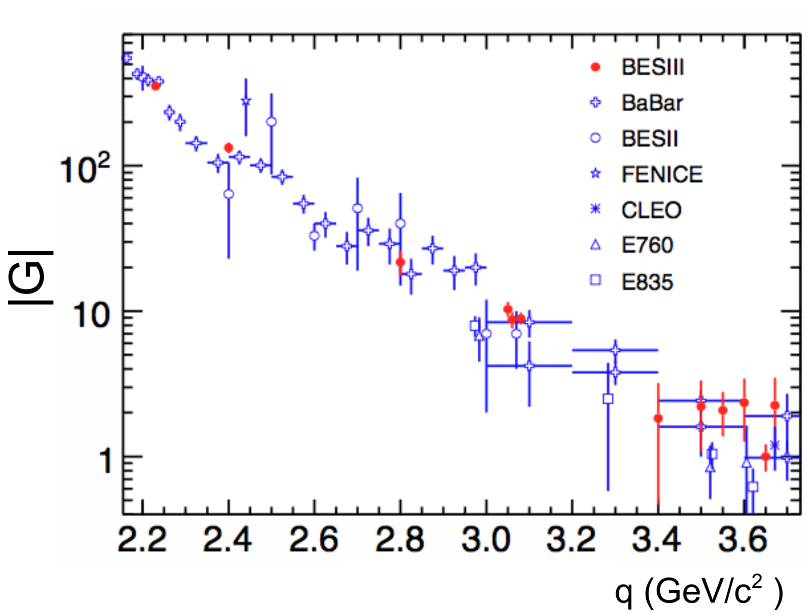
→ effective form factor

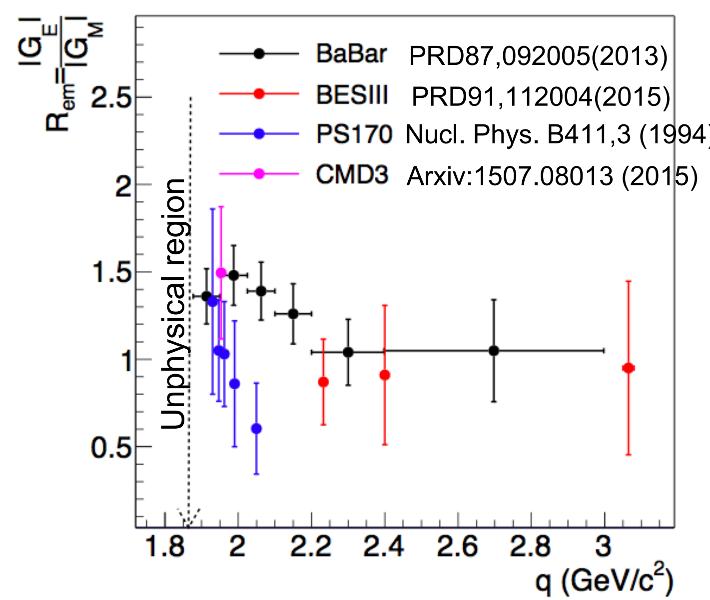
Angular analysis:
Extraction of R_{em} and $|G_{E,M}|$

$$\frac{dN}{\varepsilon\, d\cos\theta_p} = N_{norm}\left[(1+\cos^2\theta_p) + R^2_{em}\frac{1}{\tau}\sin^2\theta_p\right]$$

No steps observed in cross section. Overall uncertainty improvement by 30%

$R_{em} = |G_E|/|G_M|$ and $|G_M|$ for three E_{CM}. R_{em} consistent with BaBar and R=1. $|G_M|$ extracted for first time!



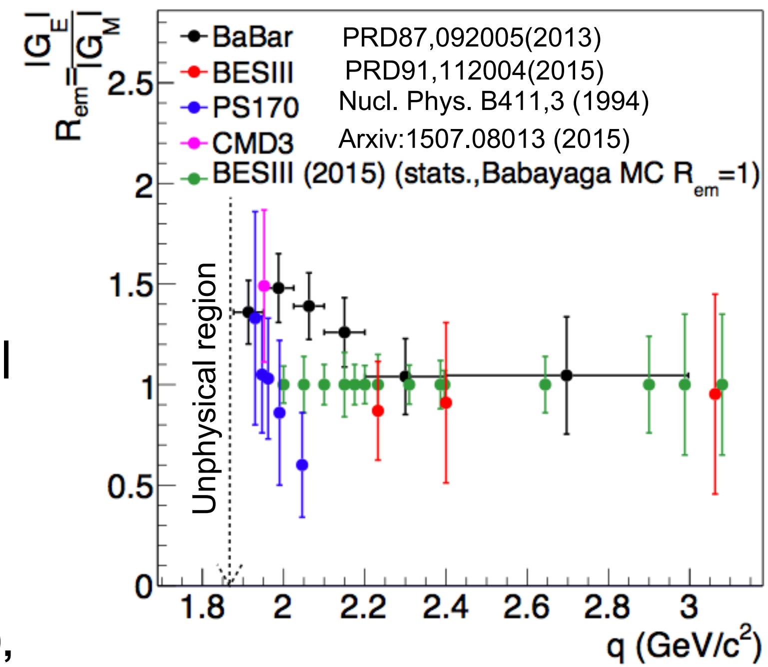


Prospects for $e^+e^- \to p\bar{p}$, $p\bar{p}\gamma_{ISR}$

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

BESIII 2015: 21 scan points between 2.0 and 3.08 GeV (552 pb^{-1})

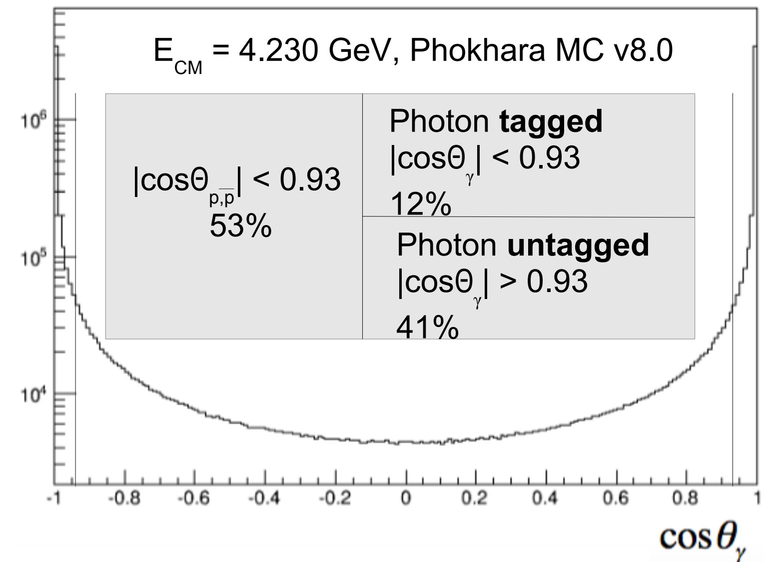
- Expected statistical **accuracies or R_{em}=$|G_E|/|G_M|$=1** between **9 % and 35%** (similar to space-like region for same q^2-region)
- Expected **accuracies for $|G_M|$ between 3 to 9%, 9 to 35 % for $|G_E|$**



$e^+e^- \to p\bar{p}\gamma_{ISR}$

Data samples (ECM): ψ(3770),ψ(4040), 4230, 4260, 4360, 4420, 4600. Total: 7.4 fb-1

- Analysis for each E_{CM} and q, then combine statistics
- ISR kinematics: photon and $p\bar{p}$-system with small opposite polar angles
- Efficiencies: ~20% -γ-untagged, ~6% γ-tagged analysis
- From 2.1 GeV up untagged-photon analysis possible
- Remaining $e^+e^- \to p\bar{p}\pi^0$ subtracted from data
- **Final statistics competitive with BaBar**



Prospects for $e^+e^- \to n\bar{n}$, $n\bar{n}\gamma_{ISR}$

Only two direct measurements of neutron effective FF

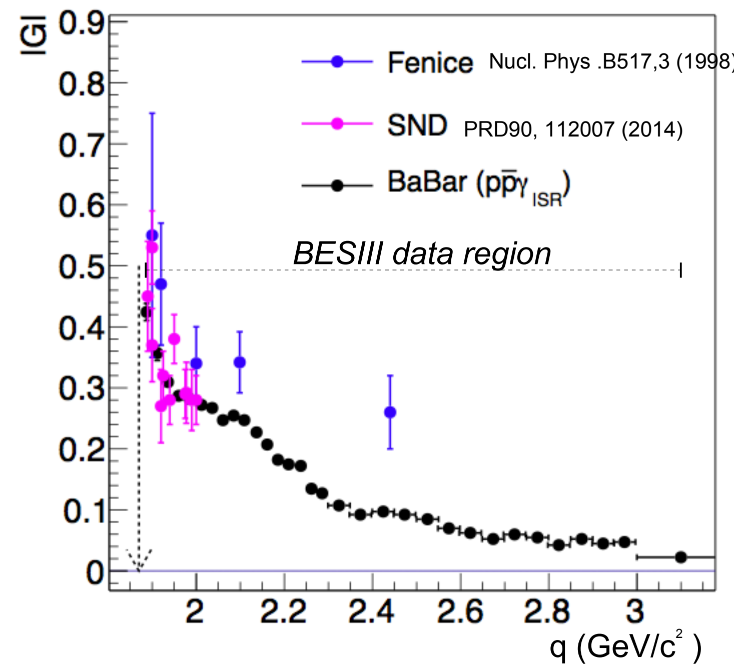
BESIII data cover wide range (1.87 – 3.08 GeV) with unprecedented statistics

→ **measurement of cross section and |G| in wide q^2-region**

→ **could provide the first measurement of R_{em}**

Strategy:

- First identification of $\bar{n}$ and γ_{ISR}: EMC shower information
- neutron identification
- event kinematics (geometry)



$e^+e^- \to n\bar{n}$

- $\bar{n}$/n detection efficiencies of ~20/30% (efficiencies up to % level)
- Main background from beam background processes
- Unprecedented statistics above 2.0 GeV (~300 evts at 2.4 GeV)

$e^+e^- \to n\bar{n}\gamma_{ISR}$

- Only tagged analysis possible (efficiencies at per mille level)
- Increase detection efficiency using TOF, MUC
- Main background from $e^+e^- \to n\bar{n}\pi^0$ and e+e- → γγ(γ) (Neural Network)

BESIII

EMC calorimeter
CsI(Tl): $15X_0$,
λ_I = 171.5 g/cm^2, ρ = 4.53 g/cm^3
→ 52% n/$\bar{n}$ interact in EMC

MUC: Iron + resistive plates
λ_I = 132.1 g/cm^2, ρ = 7.874 g/cm^3
56 cm Fe thickness in barrel
→ ~96 % n/$\bar{n}$ interact in MUC

Hyperon EM FFs in BESIII

$e^+e^- \rightarrow \Lambda\bar{\Lambda}$ (BESIII Preliminary!!)

Analysis based on 40.5 pb^{-1} collected in 4 scan points between 2.2324 – 3.08 GeV in 2012 test run

- at E_{CM} = 2.2324 GeV ($m^{th}_{\Lambda\bar{\Lambda}}$ = 2.2317 GeV)

  From $\Lambda \rightarrow p\pi^-$ and $\bar{\Lambda} \rightarrow \bar{p}\pi^+$ ($BR_{p\pi}$ = 64%)

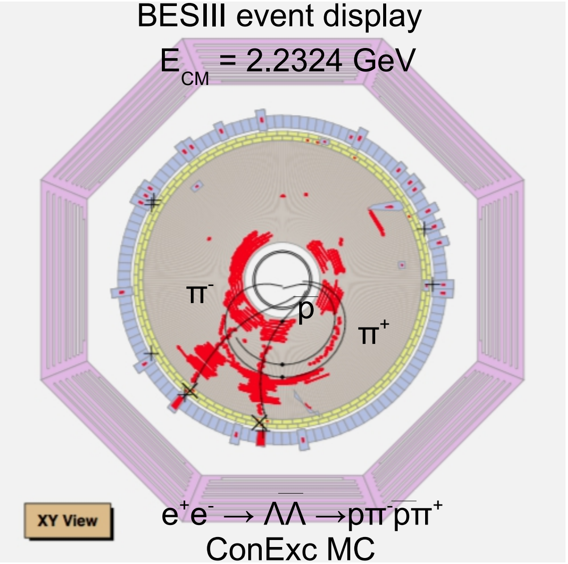
  ○ well defined p_π, possible $\bar{p}$-annihilation

  From $\bar{\Lambda} \rightarrow \bar{n}\pi^0$ ($BR_{n\pi 0}$ = 36%)

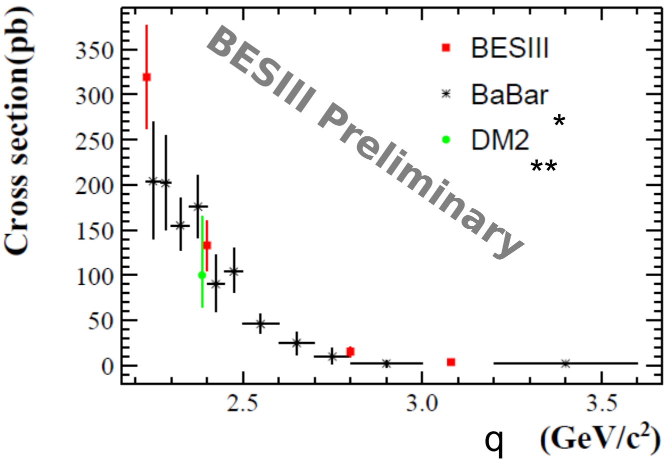
  ○ $\bar{n}$-annihilation in EMC (Neural Network), well defined $p_{\pi 0}$

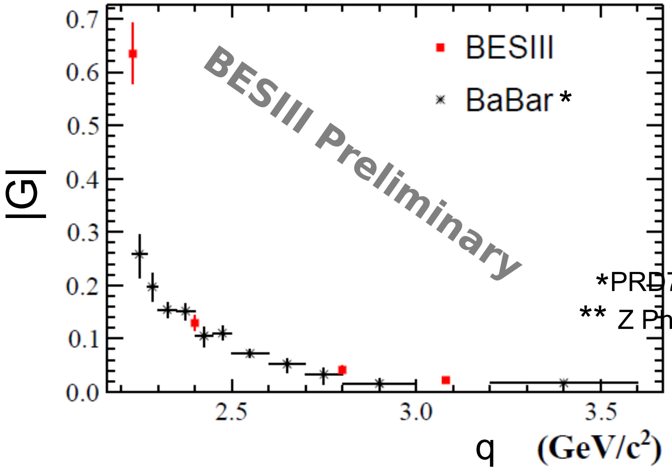
- at E_{CM} ≥ 2.4 GeV, from $\Lambda \rightarrow p\pi^-$ and $\bar{\Lambda} \rightarrow \bar{p}\pi^+$

  ○ p, $\bar{p}$, π^- and π^+ from interaction vertex, in time, $\bar{\Lambda}\Lambda$ back to back, $E_{\Lambda,\bar{\Lambda}} = E_{CM}/2$ ...



Current results improve uncertainty by at least 10% for low q^2 and even more for E_{CM} > 2.4 GeV





*PRD76,092006 (2007)

** Z Phys C48, 23(1990)

Cross section does not vanish at threshold!! → **Coulomb interaction at quark level?**

Prospects for $e^+e^- \rightarrow$ Hyperons

From 2015 scan full determination of lambda- FFs possible:

- Imaginary part of FFs leads to polarization observables:

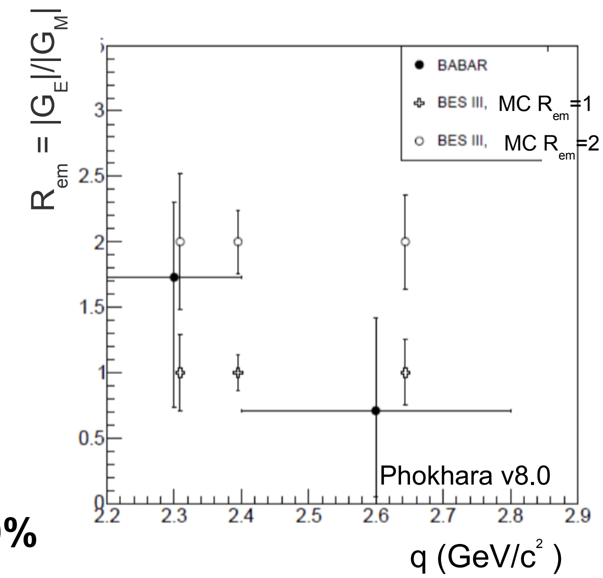
  Parity violating decay: $\Lambda \rightarrow p\pi$

$$\frac{dN}{d\cos\theta_p} \propto 1 + \alpha_\Lambda P_n \cos\theta_p \quad \text{and} \quad P_n = -\frac{\sin 2\theta \sin\Delta\phi / \tau}{R\sin^2\theta/\tau + (1+\cos^2\theta)/R} = \frac{3}{\alpha_\Lambda}\langle\cos\theta_p\rangle$$

Θ_p : Angle between proton and polarization axis in Λ-CM

Θ_Λ: Λ polar angle in CM

Φ : relative phase between G_E and G_M



Expected statistical accuracies for P_n between 6 and 17%

Expected statistical accuracies for $R_{em} = |G_E|/|G_M| = 1$ between 14 and 29%

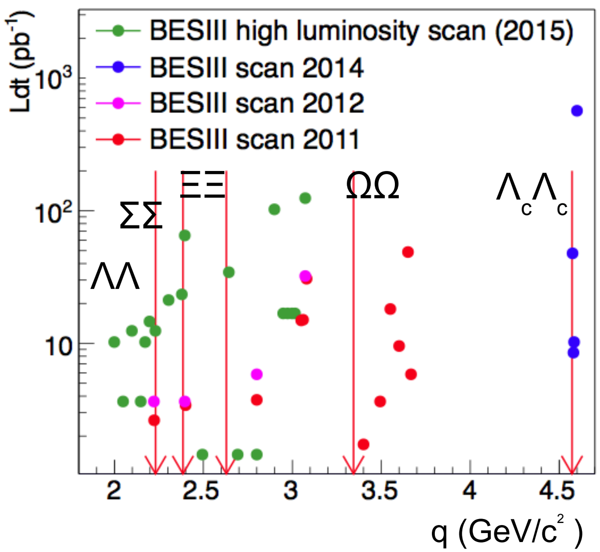
- Also available from threshold (2015, 2014, 2011 data):

  ee → $\Lambda\bar{\Sigma}^0$, $\Sigma^0\bar{\Sigma}^0$, $\Sigma^-\bar{\Sigma}^+$, $\Sigma^+\bar{\Sigma}^-$, $\Xi^0\bar{\Xi}^0$, $\Xi^+\bar{\Xi}^-$, $\Omega^+\bar{\Omega}^-$, $\Lambda_c^-\bar{\Lambda}_c^+$

measurements of effective FF and R_{em} and P_n at single energy points possible

ee → $\Lambda\bar{\Sigma}^0$, $\Sigma^0\bar{\Sigma}^0$ previously measured by BaBar, no R_{em} extraction possible

measurements of effective FF, R_{em} and $|G_M|$ at threshold possible



Pion FF in BESIII

$e^+e^- \rightarrow \pi^+\pi^-\gamma_{ISR}$ arXiv:1507.08188 (submitted to PLB)

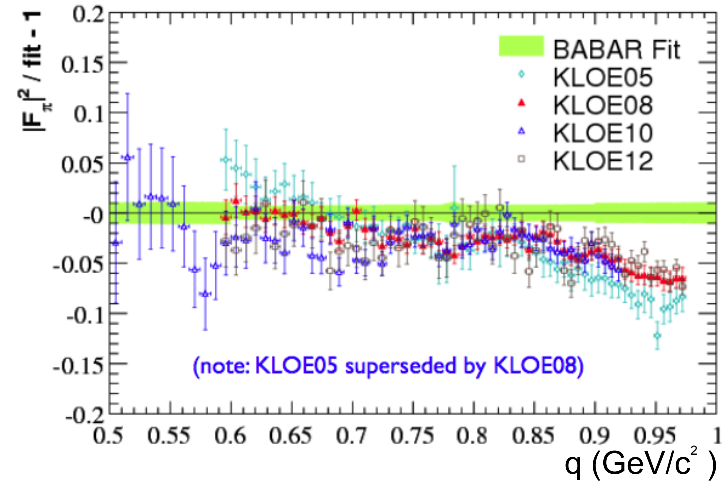
- Goal: **hadronic vacuum polarization contribution to $a_\mu = \frac{(g_\mu-2)}{2}$**

$$a_\mu^{SM} = a_\mu^{QED} + a_\mu^{weak} + a_\mu^{hadr}$$

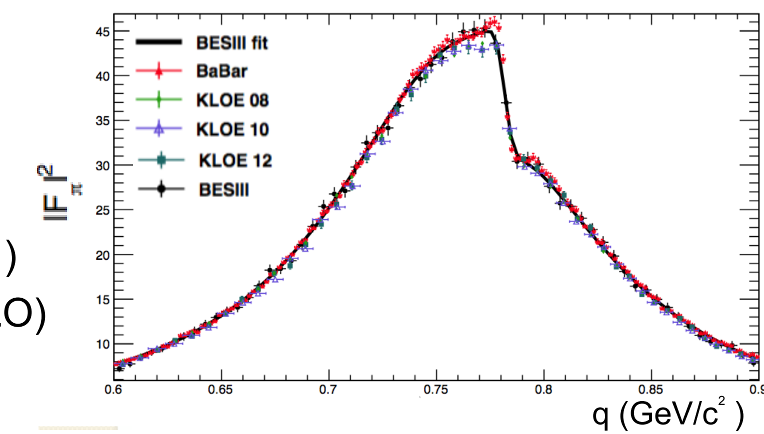
→ most relevant contribution to a_μ^{hadr} below 1 GeV: $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$

$$|F_\pi|^2(q^2) = \frac{3q^2}{\pi\alpha^2\beta^3}\sigma^{dressed}_{\pi^+\pi^-}(q^2)$$

Disagreement between existing measurements limits knowledge of a_μ



- Features of BESIII analysis:
  - 2.9 fb-1 from Ψ(3770)
  - studied range between 600 – 900 MeV
  - only tagged analysis possible below 1 GeV
  - main background from $e^+e^- \rightarrow \mu^+\mu^-\gamma_{ISR}$ prefectly understood (<1‰)
  - luminosity from BhaBha events → 0.5% accuracy (Babayaga NLO)
  - FF fit function: Gounaris-Sakurai parametrization
  - radiative corrections from Phokhara v8.0



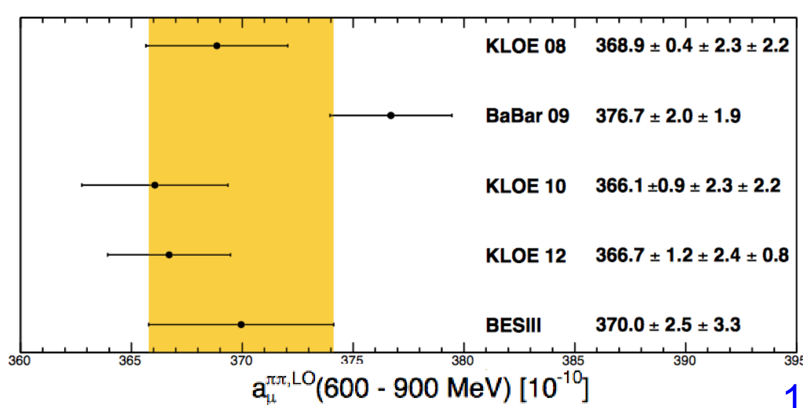
Syst. uncertainty in cross section 0.9%

Compatible with prev. measurements (1σ)

More than 3σ deviation wrt $(g_\mu\text{-}2)^{SM}$ prediction confirmed

Data from untagged analysis and above Ψ(3770) will be used

Analysis will be extended below 600 MeV and above 900 MeV



Summary

Summary & Outlook

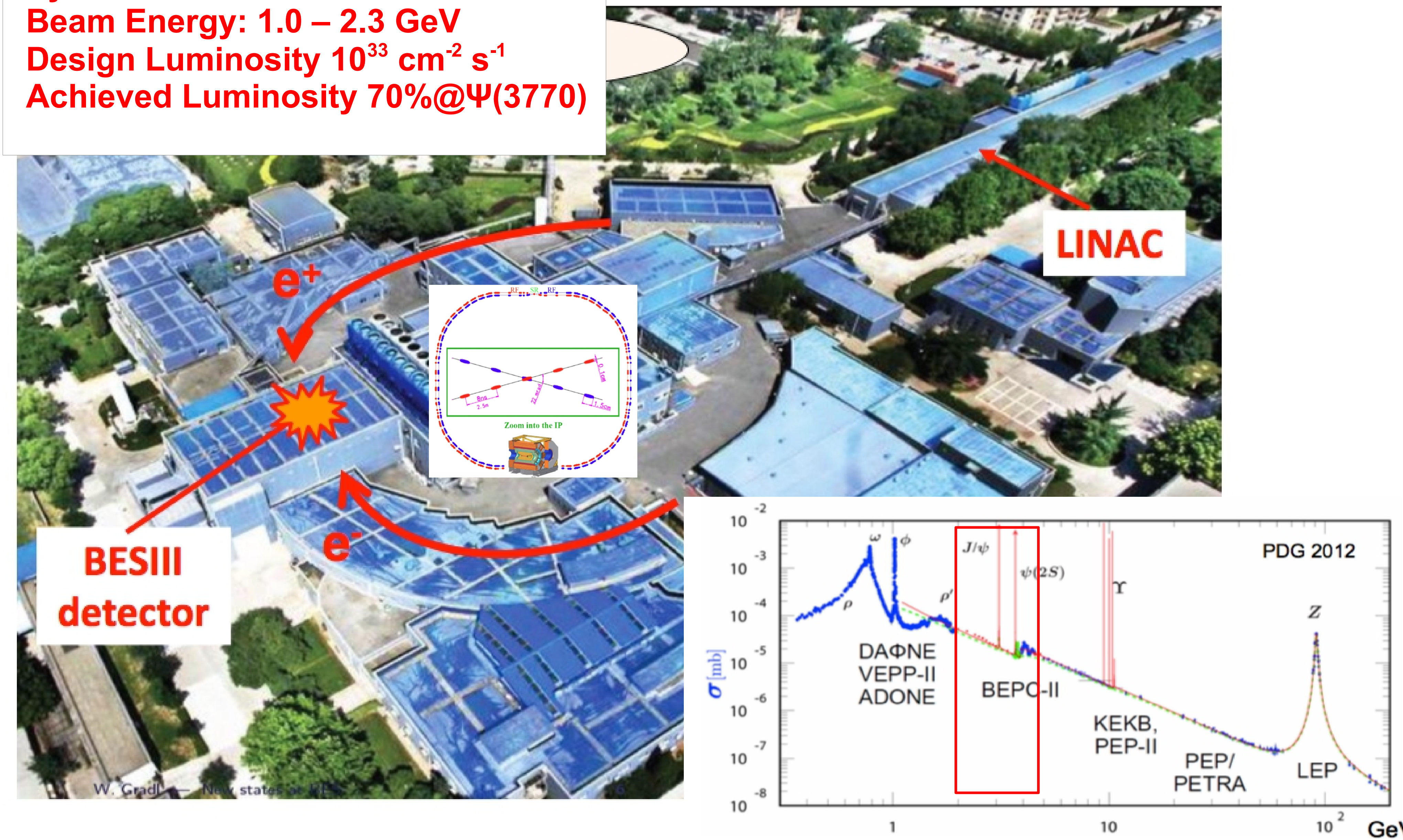
- BESIII excellent laboratory for hadron form factor measurements: scan data + ISR tecnique
- Proton Form Factors and their ratio have been measured using a small amount of data
- Preliminary results on Λ just released
- New high statistics data between 2.0 and 3.1 GeV will significantly improve FFs measurements for protons, neutrons, lambdas and other hyperons.
  Also from ISR measurements exciting results for nucleon FFs expected
- ISR technique allows access to energies below 2 GeV: the first result is the charged pion, more to come
- Other related topics being studied (not reviewed here):
  - Baryon production threshold measurements
  - Space-like transition FFs of mesons (light-by-light contributions to (g_μ-2))

Thank you!

Backup

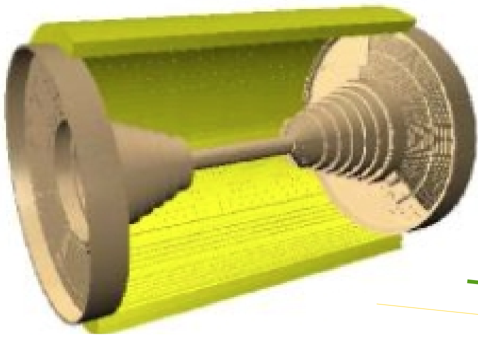
BEPCII Collider

Symmetric e^+e^--collider
Beam Energy: 1.0 – 2.3 GeV
Design Luminosity 10^{33} cm^{-2} s^{-1}
Achieved Luminosity 70%@Ψ(3770)



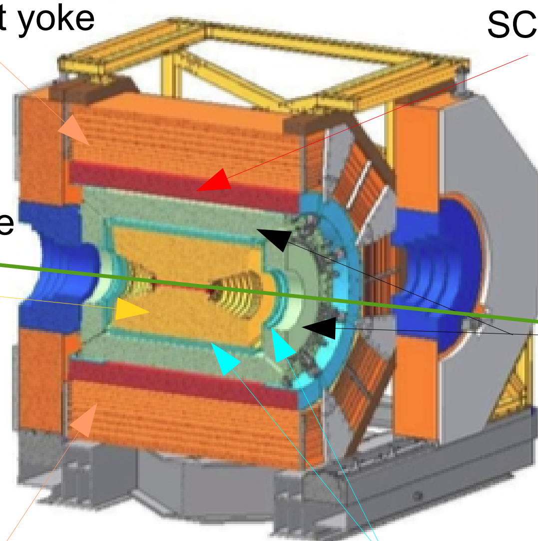
BESIII Detector

MDC

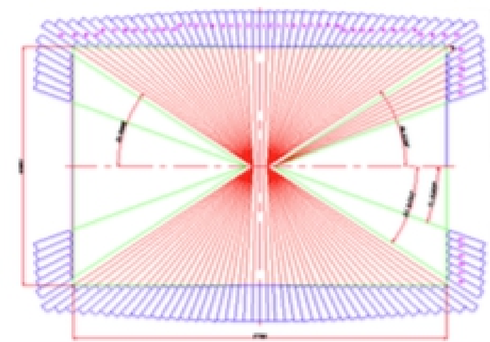


R inner: 63mm
R outer: 810 mm
Length: 2582 mm
43 Layers

$\sigma(p)/p = 0.5\%$
$\sigma_{dE/dx} = 6.0\%$



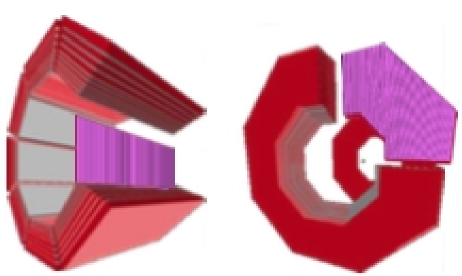
CsI(Tl) EMC



6240 CsI(Tl) crystals: 28cm (**$15X_0$**)
Barrel: $|\cos\Theta|<0.83$
Endcap: $0.85 < |\cos\Theta| < 0.93$

$\sigma(E)/E = 2.5\%$
$\sigma_{Z,\Phi}(E) = 0.5 - 0.7$ cm

RPC MUC



8 – 9 layers of RPC
p>400 MeV/c
$\delta R\Phi = 1.4 \sim 1.7$ cm

TOF

BTOF: two layers;
ETOF: 48 crys. for each

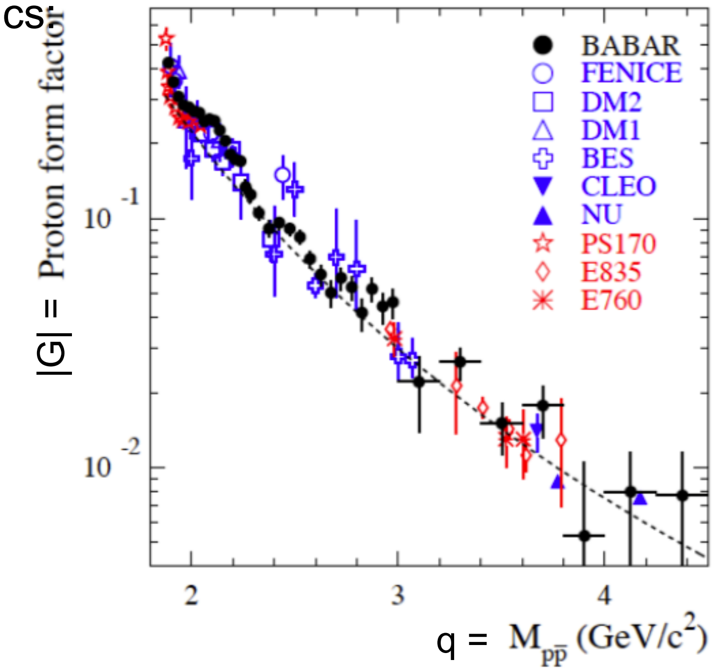
$\sigma(t) = 80$ps (barrel)
$\sigma(t) = 120$ps (endcap)

Experimental Situation: proton FFs

- Initial direct measurements of σ_{Born}(ee--> pp) had very poor statistics:
  → only extraction of **effective form factor, |G|,** possible

$$|G| = \sqrt{\frac{\sigma_{Born}}{(1+\frac{1}{2\tau})(\frac{4\pi\alpha^2\beta C}{3E_{CM}^2})}}$$

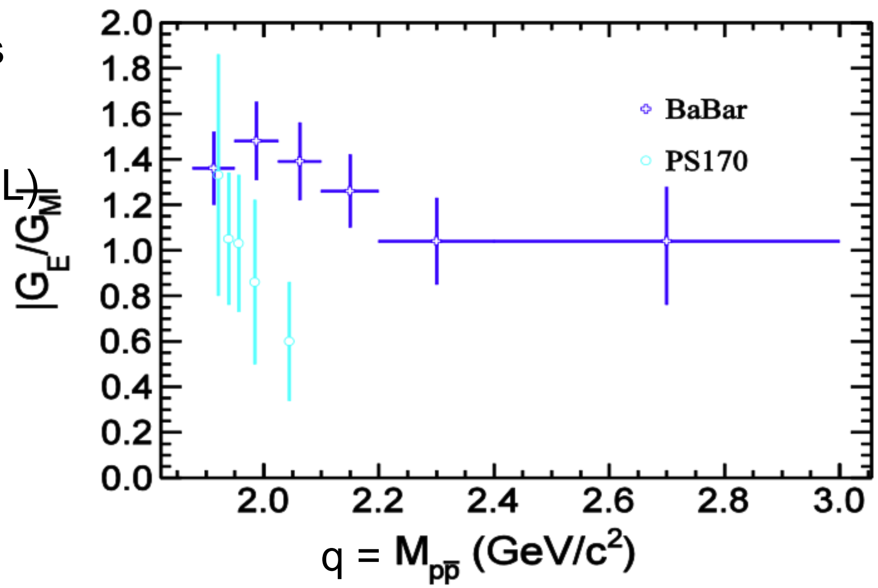
(Assumption: $|G| = |G_E| = |G_M|$)



New measurements by BaBar (ISR) and pp-experiments:

- Steep rise at threshold
- Steps near 2.25 and 3.0 GeV
- Asymptotic behavior in SL and TL regions differ:
- $|G_M^{TL}(10\ GeV^2)| = 2|G_M^{SL}(10\ GeV^2)|$

- Only BaBar and PS170 with statistics for angular analysis
  → extraction of **$R = |G_E| / |G_M|$** possible
  - Precision between 11% and 43%, (<1% precision in SL)
  - Strong tension between Babar and PS170
  - No individual determination of G_E and G_M



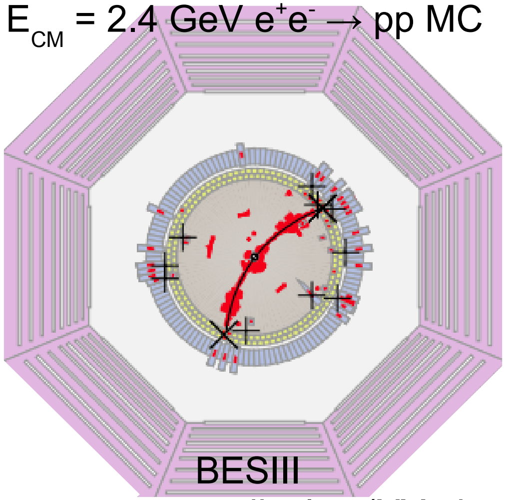
$e^+e^- \to p\bar{p}$ (Phys. Rev. D91, 112004)

Analysis based on157 pb^{-1} collected in 12 scan points between 2.22 – 3-71 GeV in 2011 and 2012

- Selection:

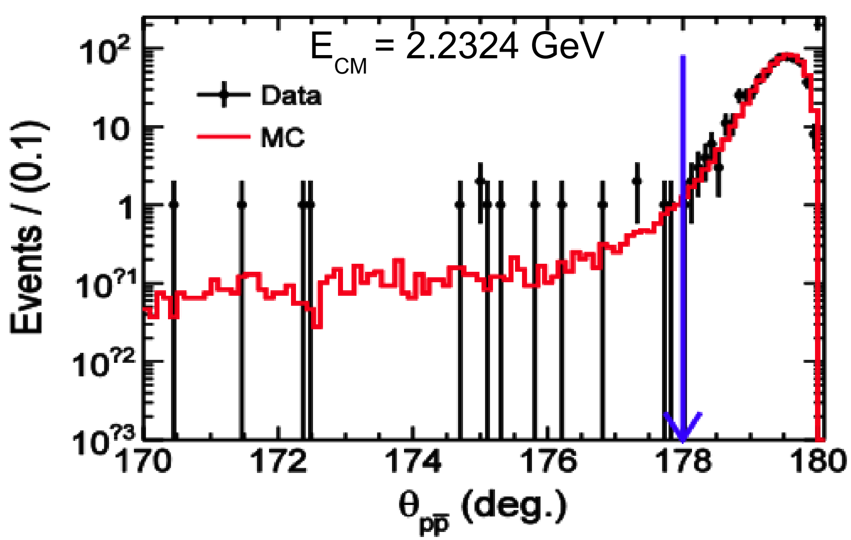
  Only 2 oppositely charged tracks in detector:

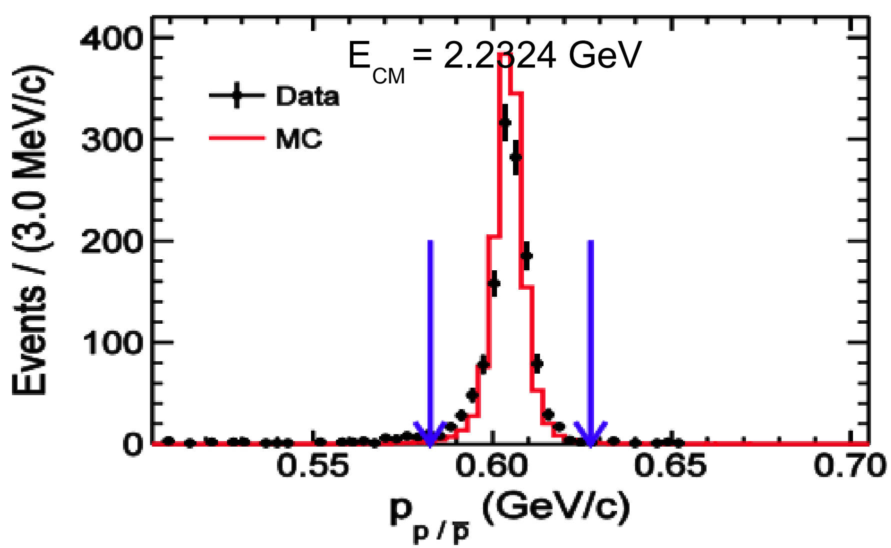
  - identified as p and p: dE/dx + Tof +E/p_p < 0.5
  - from interaction vertex: $|R_{xy}| < 1$cm, $|R_z| < 10$ cm
  - same time of flight window: |tofp – tofp|< 4ns
  - back to back signature
  - sharing E_{CM}
  - for E_{CM} > 2.4 GeV low polar angles rejected (Bhabha)



event display (XY-view)

- Background:
  - Beam background, ee--> two-body and multi-body with p and p → negligible
  - Only remaining Bhabha at E_{CM}> 3.40 GeV corrected for





$e^+e^- \rightarrow p\bar{p}$ (Phys. Rev. D91, 112004)

- Results:
  - **from σ_{Born}(ee--> pp) measurement, extraction of effective form factor, |G| :**

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

$|G| = |G_E| = |G_M|$ →

$$|G| = \sqrt{\frac{\sigma_{Born}}{(1+\frac{1}{2\tau})(\frac{4\pi\alpha^2\beta C}{3E_{CM}^2})}}$$

N_{obs} : observed signal events

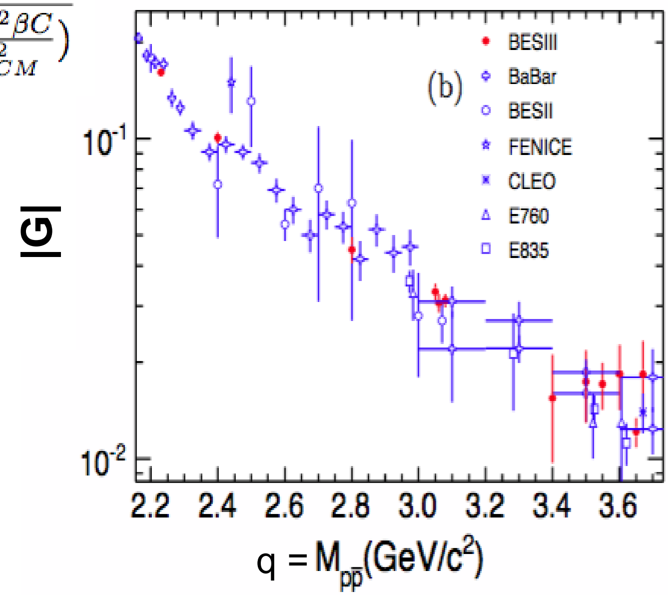
L : integrated luminosity

N_{bkg} : estimated background (from MC)

ε : detection efficiency (from MC)

1 +δ: radiative factor (from MC)

Agreement with previous measurements and overall uncertainty improved by 30%



  - **from proton angular distribution in CM: extraction of $R = |G_E|/|G_M|$ and $|G_M|$:**
    - fit differential cross section with:

$$\frac{dN}{\varepsilon \cdot d\cos\theta_p} = N_{norm}\left[(1+\cos^2\theta_p) + R^2 \; \frac{1}{\tau}\sin^2\theta_p\right]$$

$$N_{norm} = \frac{2\pi\alpha^2\beta L}{4s}\left[1.94+5.04\frac{m_p^2}{s}R^2\right] \cdot |G_M|^2$$

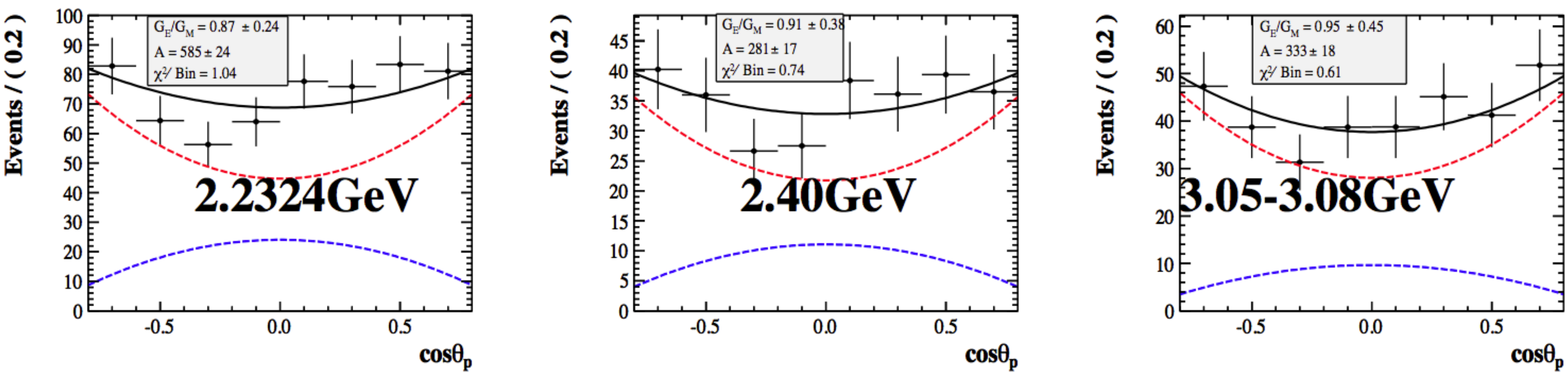
    - from second moment of $\cos\theta_p$:

$$R = \sqrt{\frac{s}{4m_p^2}\frac{\langle\cos^2\theta_p\rangle - 0.243}{0.108 - 0.648\langle\cos^2\theta_p\rangle}} \quad ; \quad \sigma_R = \frac{0.0741}{R(0.167 - \langle\cos^2\theta\rangle)^2}\frac{s}{4m_p^2}\sigma_{\langle\cos^2\theta_p\rangle}$$

e+e- → $p\bar{p}$ (Phys. Rev. D91, 112004)

Extraction of electromagnetic $|G_E/G_M|$ ratio

- Angular analysis to extract the em FFs:
  - $\frac{d\sigma}{d\Omega}(q^2) = \frac{\alpha^2\beta}{4s}|G_M(s)|^2\left[\left(1+\cos^2\theta_p\right) + R_{em}^2\frac{1}{\tau}\sin^2\theta_p\right]$
  - $R_{em} = G_E(q^2)/G_M(q^2)$
  - θ: polar angle of proton at the c.m.system
- Fit function:
  - $\frac{dN}{d\cos\theta_p} = N_{norm}\left[\left(1+\cos^2\theta_p\right) + R_{em}^2\frac{1}{\tau}\sin^2\theta_p\right]$
  - $N_{norm} = \frac{2\pi\alpha^2\beta L}{4s}\left[1.94 + 5.04\frac{m_p^2}{s}R^2\right]G_M(s)^2$ is the overall normalization

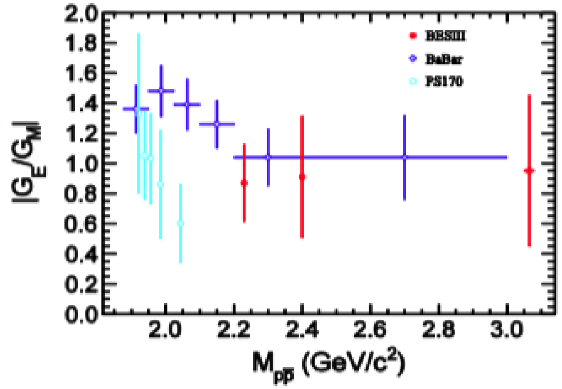


$e^+e^- \to p\bar{p}$ (Phys. Rev. D91, 112004)

Extraction of electromagnetic $|G_E/G_M|$ ratio

- **Method of Moment**
  - Second Moment of $\cos\theta_p$: $\langle\cos^2\theta_p\rangle = \frac{1}{N_{norm}}\int \cos^2\theta_p \frac{d\sigma}{d\Omega} d\cos\theta_p$
  - The estimator of $\langle\cos^2\theta_p\rangle$: $\langle\cos^2\theta_p\rangle = \overline{\cos^2\theta_p} = \frac{1}{N}\sum_{i=1}^{N}\cos^2\theta_p/\varepsilon_i$
  - Extract $|G_E/G_M|$ ratio: $R = \sqrt{\frac{s}{4m_p^2}\frac{\langle\cos^2\theta_p\rangle - 0.243}{0.108 - 0.648\langle\cos^2\theta_p\rangle}}$
  - Uncertainty of $\langle\cos^2\theta_p\rangle$: $\sigma_{\langle cos^2\theta_p\rangle} = \sqrt{\frac{1}{N-1}\left[\langle cos^4\theta_p\rangle - \langle cos^2\theta_p\rangle\right]}$
- **Results on $|G_E/G_M|$ ratio:**

$\sqrt{s}$ (MeV)	$\lvert G_E/G_M\rvert$	$\lvert G_M\rvert$ ($\times 10^{-2}$)	χ^2/ndf
	Fit on $\cos\theta_p$		
2232.4	$0.87 \pm 0.24 \pm 0.05$	$18.42 \pm 5.09 \pm 0.98$	1.04
2400.0	$0.91 \pm 0.38 \pm 0.12$	$11.30 \pm 4.73 \pm 1.53$	0.74
(3050.0, 3080.0)	$0.95 \pm 0.45 \pm 0.21$	$3.61 \pm 1.71 \pm 0.82$	0.61
	method of moment		
2232.4	0.83 ± 0.24	18.60 ± 5.38	-
2400.0	0.85 ± 0.37	11.52 ± 5.01	-
(3050.0, 3080.0)	0.88 ± 0.46	3.34 ± 1.72	-

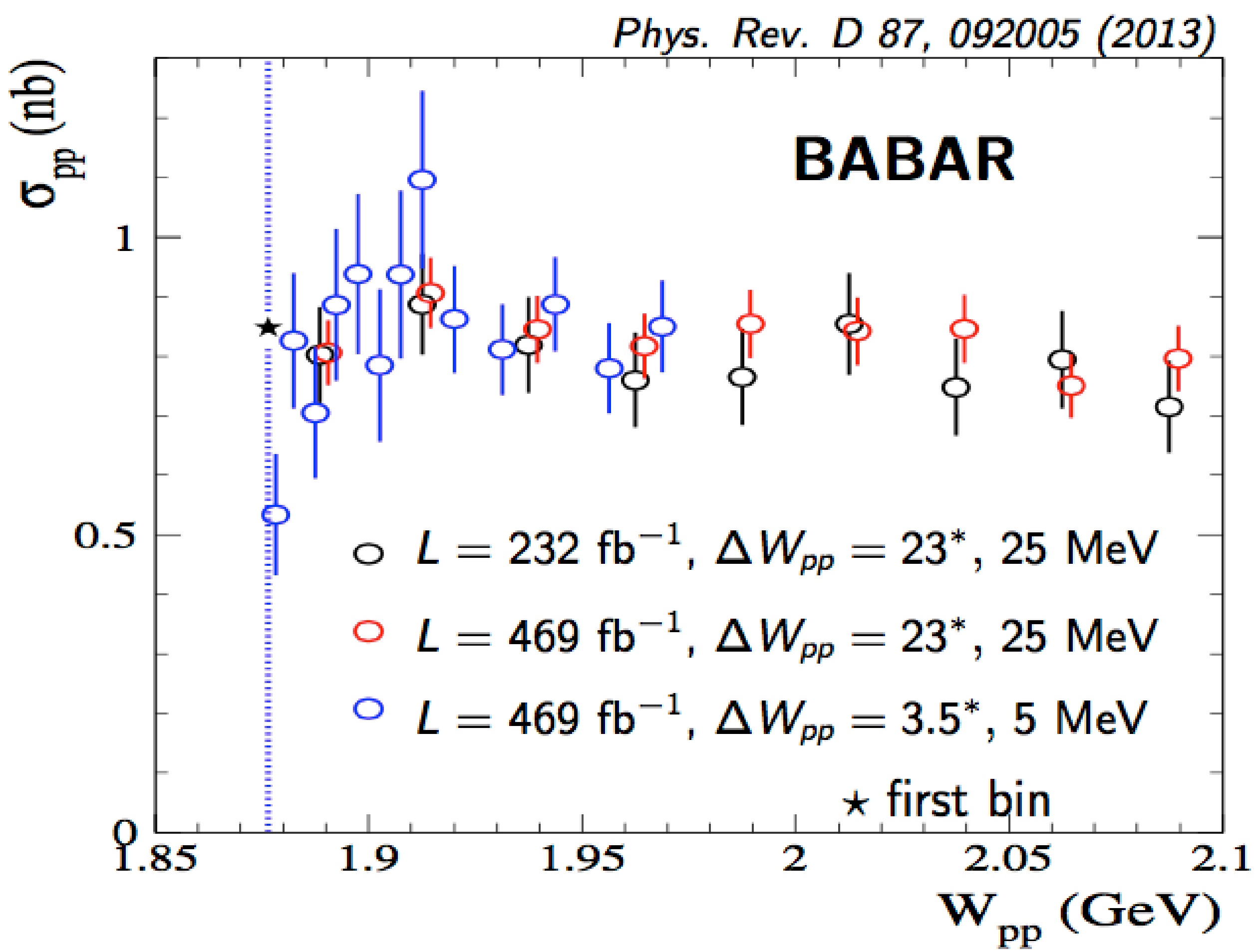


Accepted by Phys. Rev. D
arXiv:1504.02680

Proton threshold

At $p\bar{p}$ threshold ($q^2 = 4M_p^2$)

S. Pacetti



With more L and smaller binning, the result changed somewhat.

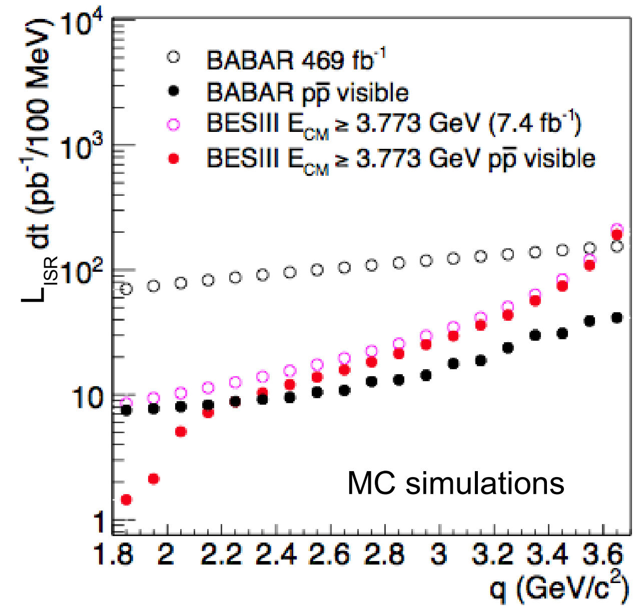
Results from BESIII needed (from ISR process).

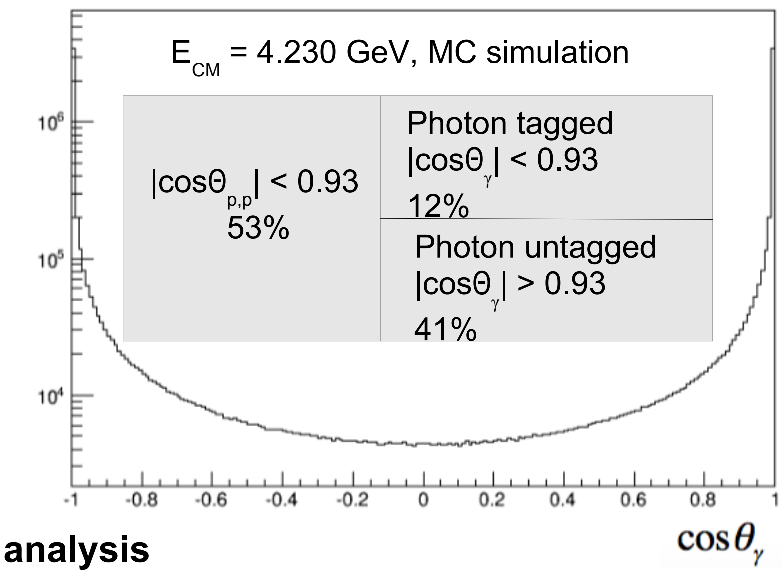
Prospects for $e^+e^- \to p\bar{p}\gamma_{ISR}$

Available data samples (E_{CM}): ψ'',ψ(4040), Y(4230), Y(4260), Y(4360), Y(4420), Y(4600). Total: 7.4 fb-1

Strategy:
for each E_{CM}
tagged and
untagged analysis

- dN(ppγ)/dq
- Efficiencies, background, radiative factor, (functions dependent on q)
- Add all corrected data from different E_{CM} for each q-bin
- Normalize with L_{ISR}
- Born cross section, Effective form factor
- Angular analysis: **Extraction of R and $|G_{E,M}|$**



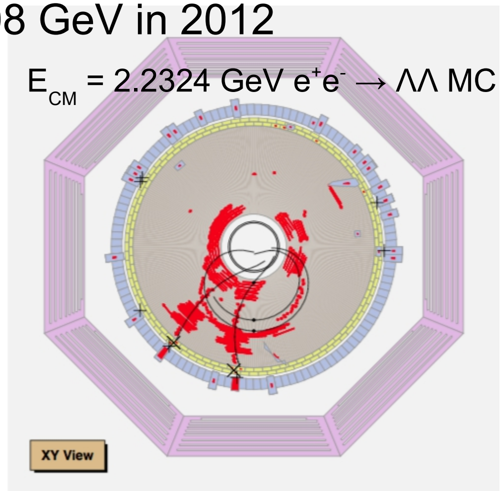


For q > 2.1 GeV: **Large efficiencies (~20%) from untagged photon analysis** provide large statistics and **better $|G_E|/|G_M|$ accuracies**

For q < 2.1 GeV: **Only tagged measurement possible** for E_{CM} ≥ 3.773 GeV.
Low efficiencies (~6%), lower statistics than BaBar. Perhaps untagged analysis of J/ψ and ψ(3686) possible ?!

$e^+e^- \to \Lambda\bar{\Lambda}$ (BESIII Preliminary!!)

Analysis based on 40.5 pb^{-1} collected in 4 scan points between 2.2324 – 3.08 GeV in 2012



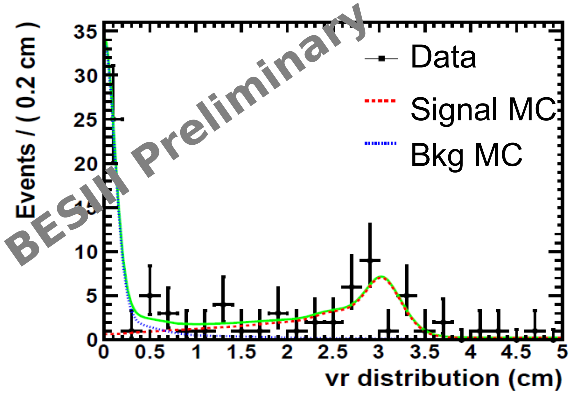
- Selection at E_{CM} = 2.2324 GeV ($m_{\Lambda\Lambda}$ = 2.2317 GeV)

  Reconstruction of ee-->$\Lambda\bar{\Lambda}$ from $\Lambda \to p\pi^-$ and $\bar{\Lambda} \to \bar{p}\pi^+$ (BR 64%)
  - only pi and pi in detector
  - pion-momentum well defined
  - Anti-proton annihilation--> secondary particles $|R_r|$ ~3 cm

  → 43 ± 7 events observed

  Reconstruction of ee-->$\Lambda\bar{\Lambda}$ from $\bar{\Lambda} \to \bar{n}\pi^0$:(BR 36%)
  - Multivariate Analysis (boosted decision tree) to identify n
  - $p_{\pi 0}$ well defined

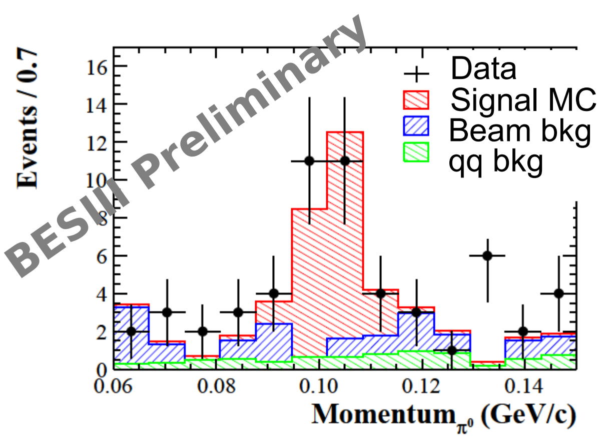
  → 22 ± 6 events observed



- At E_{CM} = 2.4, 2.8 and 3.08 GeV

  Reconstruction of ee-->$\Lambda\bar{\Lambda}$ from $\Lambda \to p\pi^-$ and $\bar{\Lambda} \to \bar{p}\pi^+$

  Only 4 oppositely charged tracks in detector:
  - identified as p, $\bar{p}$, π^- and π^+
  - from interaction vertex
  - $\Lambda\bar{\Lambda}$ invariant mass cut
  - $\Lambda\bar{\Lambda}$ back to back signature
  - sharing E_{CM}



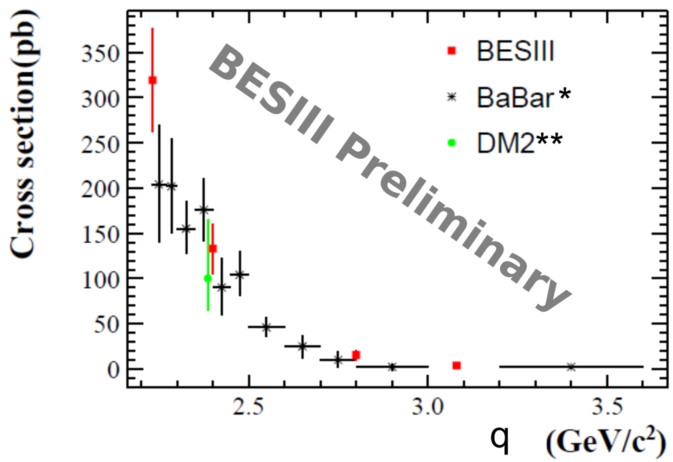
$e^+e^- \rightarrow \Lambda\bar{\Lambda}$ (BESIII Preliminary!!)

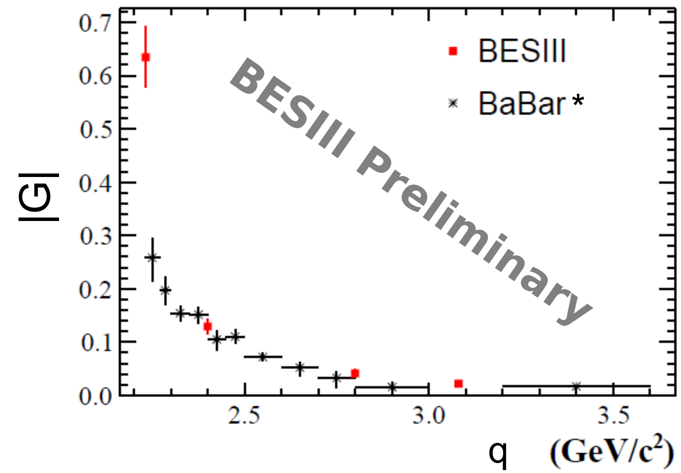
- Results:
  - from $\sigma_{Born}(ee \to \Lambda\bar{\Lambda})$ measurement, extraction of effective form factor, |G| :

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

$|G| = |G_E| = |G_M|$ →

$$|G| = \sqrt{\frac{\sigma_{Born}}{(1+\frac{1}{2\tau})(\frac{4\pi\alpha^2\beta}{3E^2_{CM}})}}$$





*PRD76,092006 (2007)
** Z Phys C48, 23(1990)

Cross section expected to vanish at threshold ($q = 2m_\Lambda$):

$$\sigma_{Born}(q^2) = \frac{4\pi\alpha^2\beta}{3\,q^2}\left[\left|G_M(q^2)\right|^2 + \frac{1}{2\tau}\left|G_E(q^2)\right|^2\right]$$ with $\beta = \sqrt{1 - 4m_\Lambda^2/q^2}$

$\sqrt{s}$ 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	320 ± 58	63.4 ± 5.7
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		$3.9 \pm 1.1 \pm 0.5$	$2.21 \pm 0.31 \pm 0.14$

Coulomb interaction at quark level?

Prospects for $e^+e^- \to \Lambda\Lambda, \Sigma\Sigma, \Xi\Xi...$

From BESIII 2015: 15 points above llbar threshold!

Parity violating decay: $\Lambda \to p\pi$, emission of proton depends on Λ-polarisation

$$\frac{dN}{d\cos\theta_p} \propto 1 + \alpha_\Lambda P_n \cos\theta_p^{(*)}$$

(*) Angle between proton a
polarization axis in mother'
rest frame

- Imaginary part of FFs leads to polarization observables:

$$P_n = -\frac{\sin 2\theta \sin\Delta\phi / \tau}{R\sin^2\theta_\Lambda/\tau + (1+\cos^2\theta_\Lambda)/R} = \frac{3}{\alpha_\Lambda}\langle\cos\theta_p\rangle$$

Expected statistical accuracies for P_n between 6 and 17%

- Expected statistical accuracies for $R = |G_E|/|G_M| = 1$ between 14 and 29%

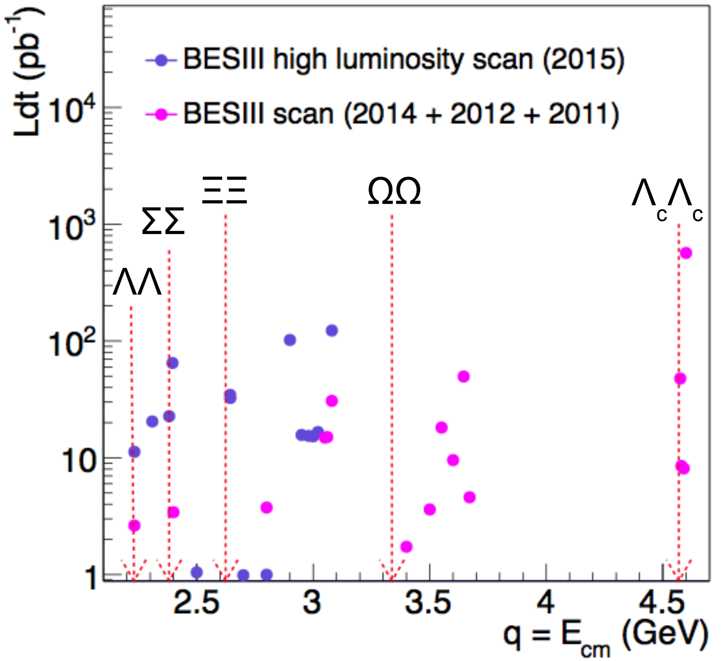
Complete determination of TL Ffs possible!!

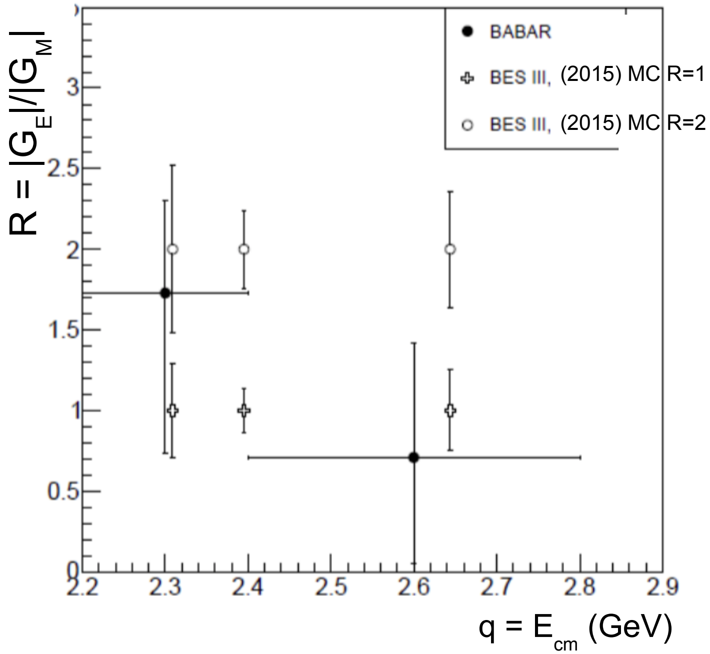
Also available from threshold:

$$ee \to \Lambda\bar{\Sigma}^0, \Sigma^-\bar{\Sigma}^+, \Sigma^0\bar{\Sigma}^0, \Sigma^-\bar{\Sigma}^+, \Xi^0\bar{\Xi}^0, \Xi^+\bar{\Xi}^-, \Omega^+\bar{\Omega}^-, \Lambda_c\bar{\Lambda}^+_c$$

$p\pi$, $p\pi^0$, $\gamma\Lambda$, $n\pi^-$, $\Lambda\pi^0$, $\Lambda\pi$, ΛK, $\Lambda\pi$,

64%, 52%, 100%, 100%, 100%, 100%, 68%, 1%





Hyperon TL EM FF in BESIII

UPPSALA UNIVERSITET

Prospects for BES III

Other hyperon channels: $\Lambda\overline{\Sigma}^0$, $\Sigma^0\overline{\Sigma}^0$

$E_{e^+e^-}$ (GeV)	L (pb^{-1})	$\epsilon_{\Lambda\overline{\Sigma^0}}$ (%)	$\sigma_{\Lambda\overline{\Sigma^0}}$ (pb)	$N_{\Lambda\overline{\Sigma^0}}$	$\epsilon_{\Sigma^0\overline{\Sigma^0}}$ (%)	$\sigma_{\Sigma^0\overline{\Sigma^0}}$ (pb)	$N_{\Sigma\overline{\Sigma^0}}$	BABAR
2.309	20	4	374	123				
2.386	20	8	40	26	4	351	115	
2.395	55	8	40	72	7	100	158	10.3±4.3
2.644	65	15	6	24	15	25	100	6.5±3.5
2.9	100	17	2	14	17	3.4	24	1.4±3.3
2.981	15	17	1.5	1.6	17	3.0	3	

- Luminosities from this proposal
- Acceptances from $J/\psi \rightarrow Y\overline{Y}$ (PRD 86 032008)
- Cross sections from:
  - BABAR (away from threshold)
  - Rinaldo Baldini (at threshold)

=> More than 10-fold increase of statistics.

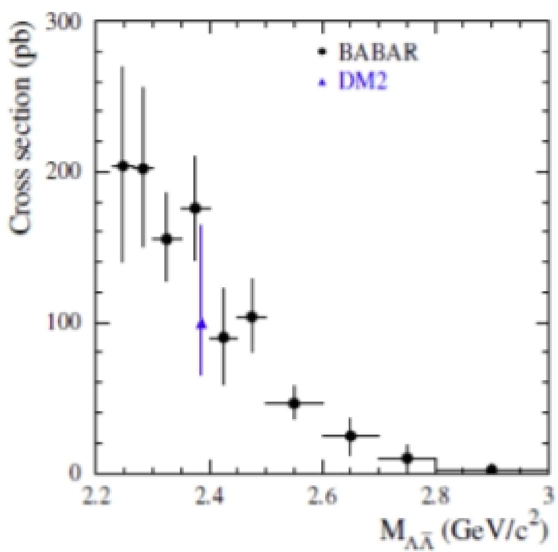
For $\Sigma^+\overline{\Sigma}^-$:

- Cross section should be larger than for $\Sigma^0\overline{\Sigma}^0$
- Acceptance of the same order

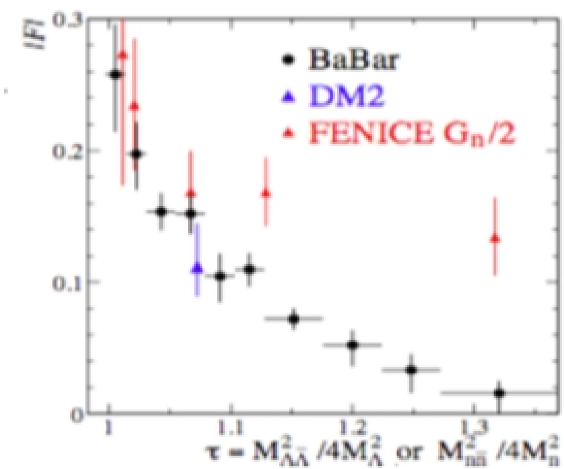
e+e- → Hyperons

[B. Aubert et al., Phys. Rev. D 76, 092006 (2007)]

About 350 $\Lambda\bar{\Lambda}\gamma_{ISR}$ events with $\Lambda \rightarrow p\pi^-$ and $\bar{\Lambda} \rightarrow \bar{p}\pi^+$ selected by BaBar



- Only one measurement before by DM2
- **Cross section roughly flat at threshold** and **possibly not vanishing** even thogh no Coulomb correction for neutral baryons production
- However, large error bars do not exclude $\sigma_{threshold} = 0$



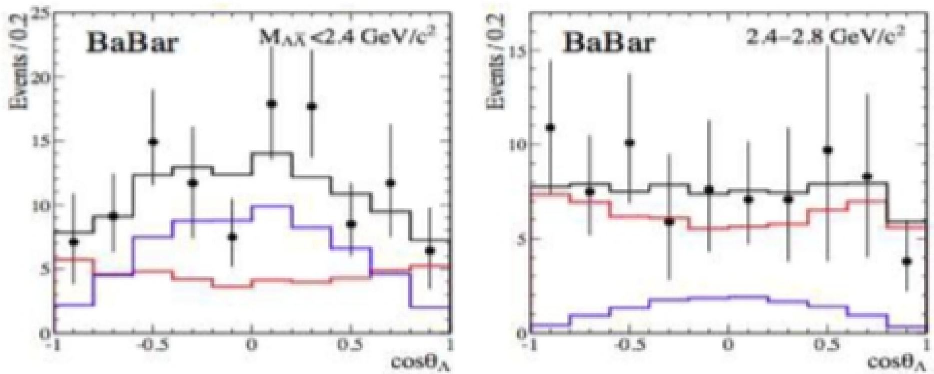
- **Rise of FFs close to threshold** observed also in this case
- Fit with $f = K/q^n$ gives $n = 9.2 \pm 0.3$
  - → pQCD asymptotic prediction (q^4) reached at 3GeV first
- F_Λ in agreement with DM2 and with F_n by Fenice

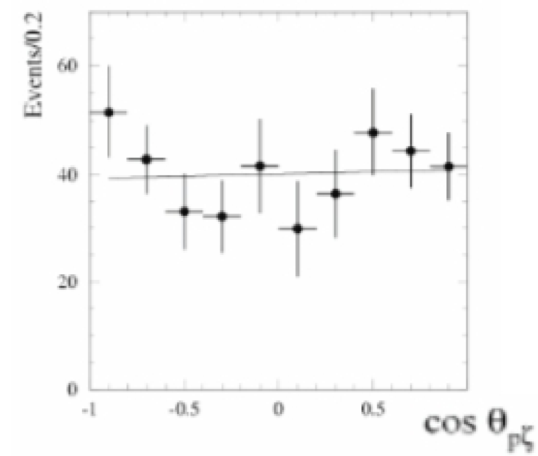
e+e- → Hyperons

[B. Aubert et al., Phys. Rev. D 76, 092006 (2007)]

- **Ratio of form factors** extracted from the analysis of the angular distribution of the lambda helicity angle

(2.23–2.40 GeV)/c^2 (2.40–2.80 GeV)/c^2





$|G_E^\Lambda/G_M^\Lambda| < 1.73^{+0.99}_{-0.57}$ $|G_E^\Lambda/G_M^\Lambda| < 0.71^{+0.66}_{-0.71}$

→ Compatible with $|G_E^\Lambda/G_M^\Lambda| = 1$, but with large uncertainties

- **Polarization** tested by fitting slope of angle between lambda polarization axis and proton momentum in Λ rest frame

$$\frac{dN}{d\cos\theta_{p\zeta}} = A(1 + \alpha_\Lambda \zeta_f \cos\theta_{p\zeta})$$

==> $-0.22 < \zeta_f < 0.28$ (90% CL)

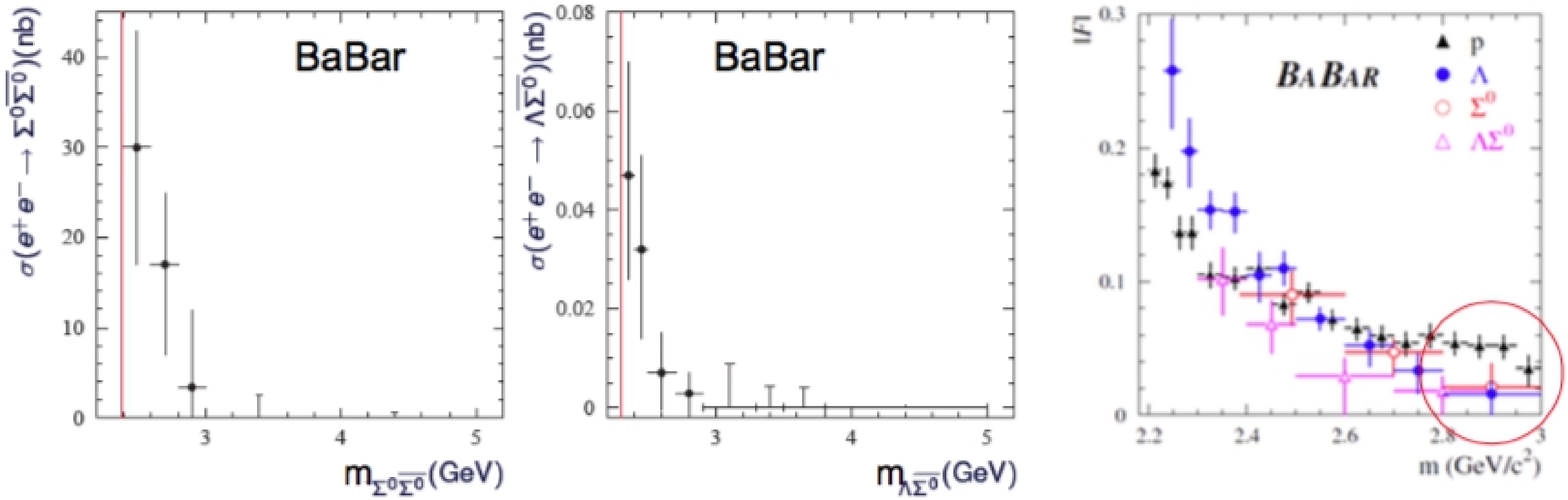
Under $|G_E^\Lambda| = |G_M^\Lambda|$ assumption, tests a **non-zero relative phase** between G_E^Λ and G_M^Λ: $-0.76 < \sin\phi < 0.98$

e+e- → Hyperons

[B. Aubert et al., Phys. Rev. D 76, 092006 (2007)]

BaBar performed first measurement ever for these channels

Reconstruct Σ baryon in decay channels $\Sigma \to \Lambda\gamma$ and $\Lambda \to p\pi$: few tens of signal events



- $\sigma(e^+e^- \to \Sigma^0\overline{\Sigma^0})$ is different from zero at threshold, being 0.030 ± 0.013 nb
- $\sigma(e^+e^- \to \Lambda\overline{\Sigma^0})$ is different from zero at threshold, being 0.047 ± 0.022 nb

QCD predictions:

$F_\Lambda/F_p = 0.24$

$F_\Sigma/F_\Lambda = -1.18$

$F_{\Sigma\Lambda}/F_\Lambda = -2.34$

- Effective |F| shows same rising behavior
- Data seem to agree with theory only for F_Σ/F_Λ (by accident?)
- F_Λ/F_p decrease with energy, similar to prediction close to 3 GeV

[Chernyak et al. Z. Phys. C 42, 569 (1989)]

New scan in 2 – 3.1 GeV

- 2014.12.30-2015.5.1;
- From high to low;
- Added 2.05 GeV;
- 20 energy points, total online luminosity 525 pb^{-1};
- Allows for form factor measurements, threshold studies, …

E_{cm} (GeV)	E_{th} (GeV)	L_{Needed} (pb^{-1})	t_{beam} ($days$)	Purpose
2.0		$\geq$8.95	14.6	Nucleon FFs
2.1		10.8	14.8	Nucleon FFs
2.15		2.7	2.29	Y(2175)
2.175		10(+)	8.5	Y(2175)
2.2		13	11	Nucleon FFs, Y(2175)
2.2324	2.2314	11	4	Hyp threshold ($\Lambda\bar{\Lambda}$)
2.3094	2.3084	20	16	Nucleon & Hyp FFs Hyp Threshold ($\Sigma^0\bar{\Lambda}$)
2.3864	2.3853	20	8.7	Hyp Threshold ($\Sigma^0\bar{\Sigma}^0$) Hyp FFs
2.3960	2.3949	$\geq$64	27.8	Nucleon & Hyp FFs Hyp Threshold ($\Sigma^-\bar{\Sigma}^+$)
2.5		0.4895	8h	R scan
2.6444 2.6464	2.6434	65	18	Nucleon & Hyp FFs Hyp Threshold ($\Xi^-\bar{\Xi}^+$)
2.7		0.5542	4.2h	R scan
2.8		0.6136	4h	R scan
2.9		100	18.5	Nucleon & Hyp FFs
2.95		15	2.8	$m_{p\bar{p}}$ step
2.981		15	2.8	η_c , $m_{p\bar{p}}$ step
3.0		15	2.8	$m_{p\bar{p}}$ step
3.02		15	2.8	$m_{p\bar{p}}$ step
3.08		120	13.2	Nucleon FFs (+30 pb^{-1})

6-month plan, finished in ~4 months.