PANDA Collaboration Meeting
EMP session

2009 December, 8 – GSI

Time-like Form Factors @ BESIII

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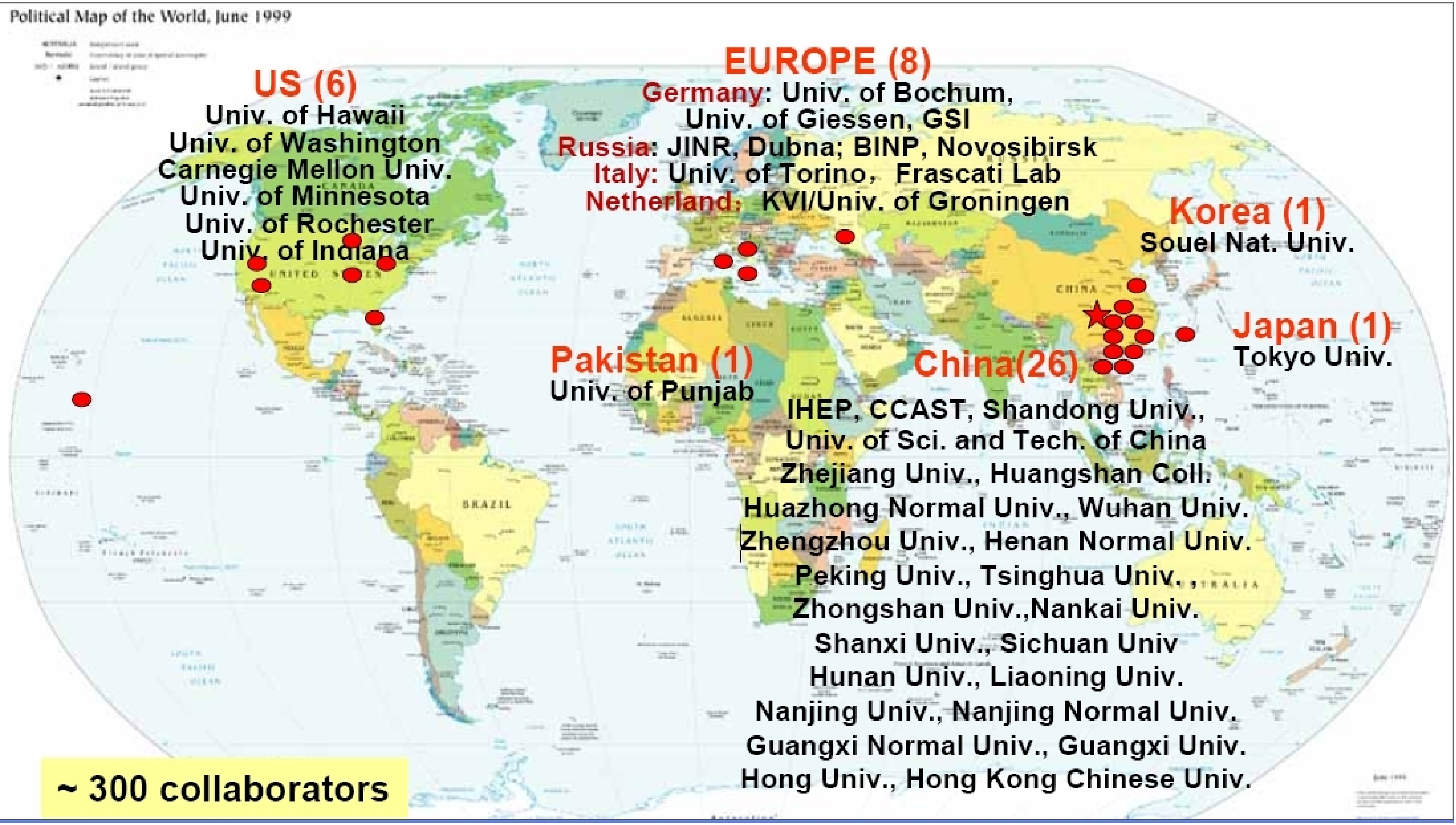
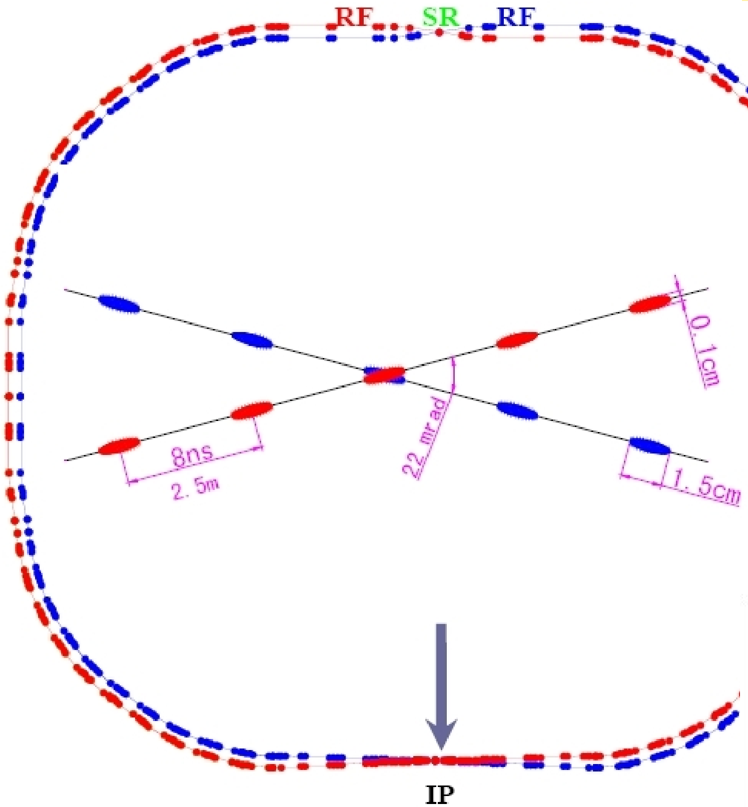
BESIII Collaboration



BEPCII and BESIII @ IHEP

BEPCII: e^+e^- double ring collider

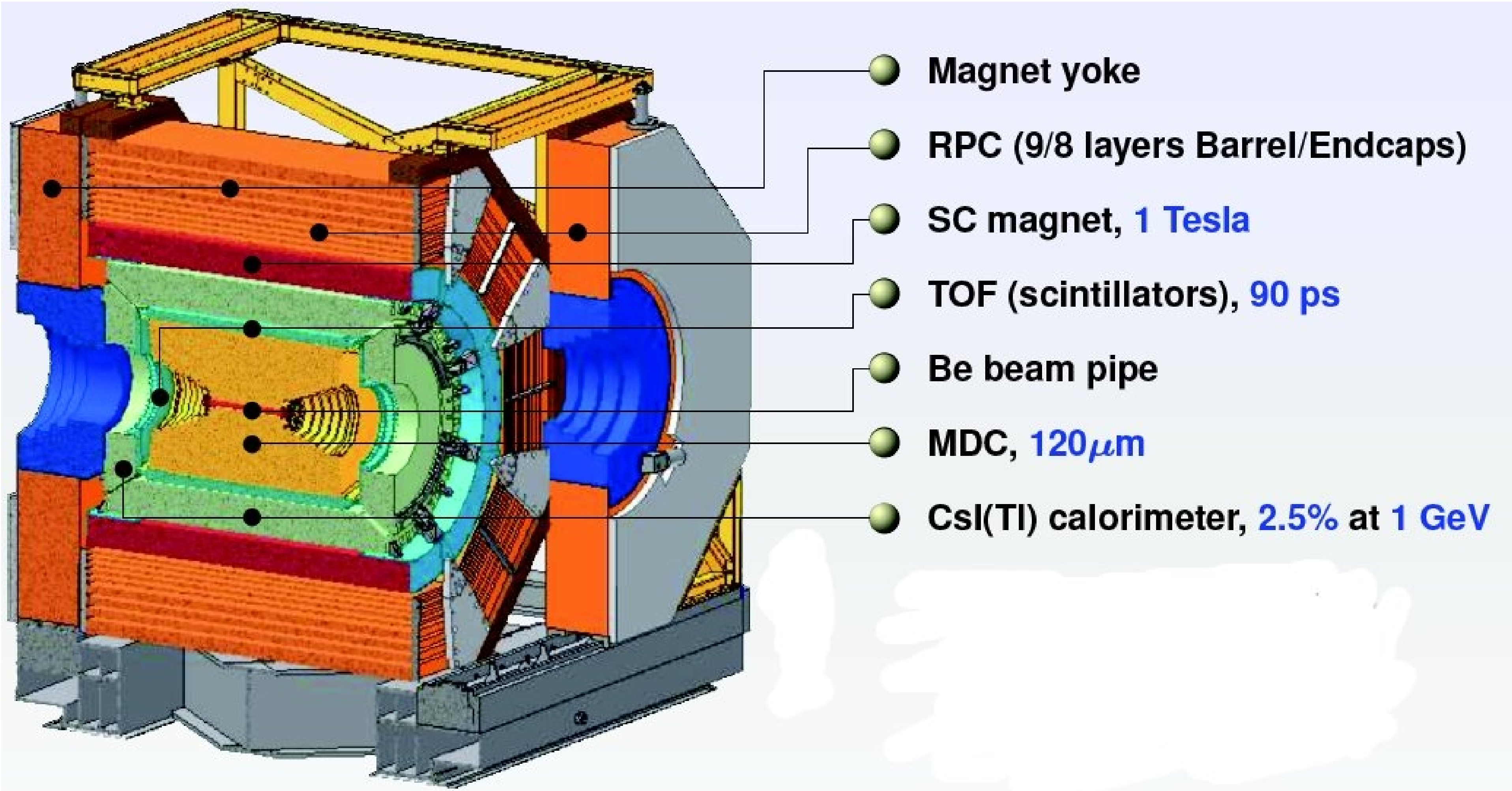


Design Features

- Beam energy: 1.0 - 2.3 GeV
- Crossing angle: 22 mrad (DAΦNE 50 mrad)
- Luminosity: 10^{33} $cm^{-2}s^{-1}$
- Optimum energy: 1.89 GeV
- Energy spread: 5.16×10^{-4}
- # of bunches: 93
- Bunch length: 1.5 cm
- Total current: 0.91 A

parameters	design	Achieved	
		BER	BPR
Energy (GeV)	1.89	1.89	1.89
Beam curr. (mA)	910	650	700
Bunch curr. (mA)	9.8	>10	>10
Bunch number	93	93	93
RF voltage	1.5	1.5	1.5
*ν_s @1.5MV	0.033	0.032	0.032
β_x^*/β_y^* (m)	1.0/0.015	~1.0/0.016	~1.0/0.016
Inj. Rate (mA/min)	200 e^-/ 50 e^+	>200	>50
Lum. ($10^{33}cm^{-2}s^{-1}$)	1	0.30	

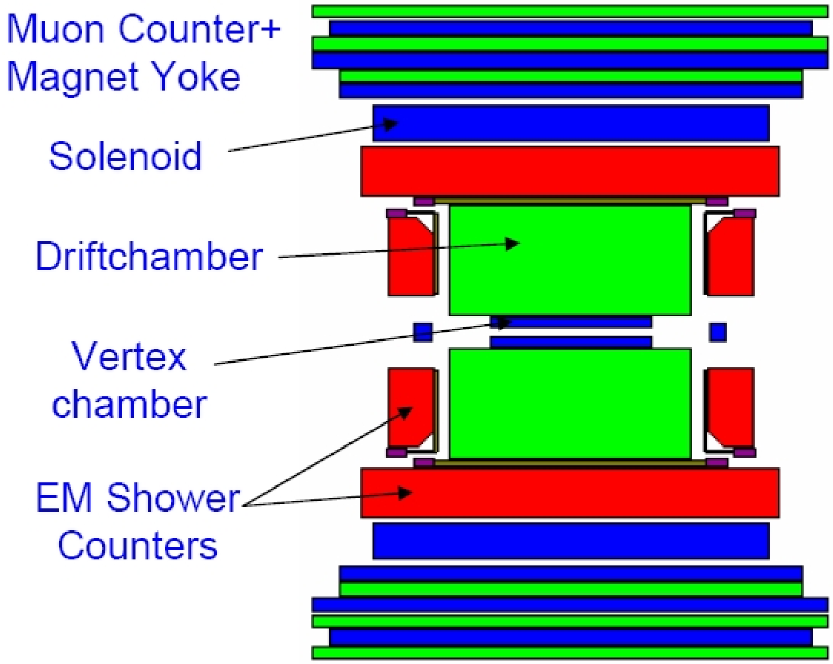
BESIII detector



A dramatic improvement!

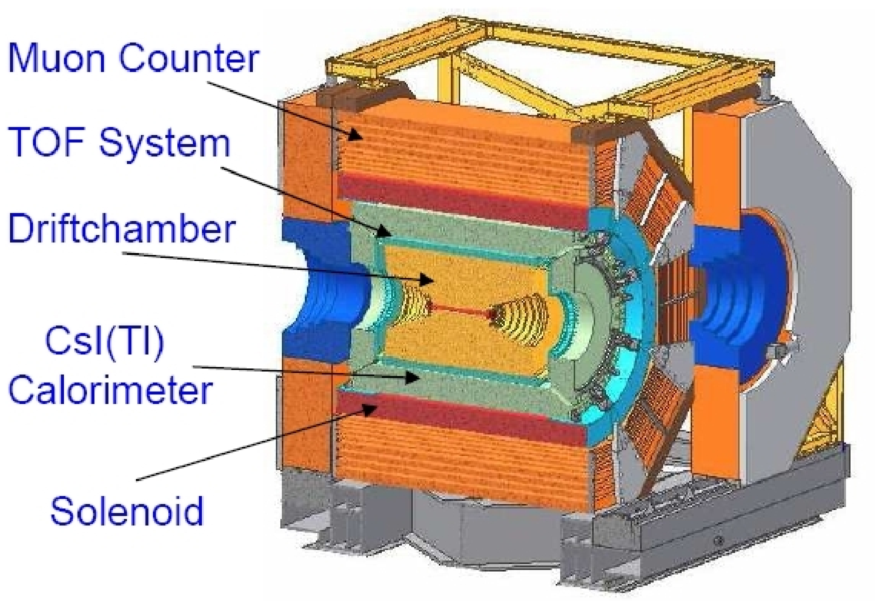
BES detectors

BESII @ BEPC



Device	Performance
MDC	$\sigma_p/p = 1.7\%\sqrt{1+p^2},\ dE/dx = 8\%$
TOF	180 ps (bhabha)
EMC	$\sigma_E/E < 22\%/\sqrt{E}$
MUC	3 layers
Magnet	0.4 T Solenoidal

BESIII @ BEPCII



Device	Performance
MDC	$\sigma_{p_t}/p_t = 0.5\%,\ dE/dx < 6\%$
TOF	90 ps (bhabha)
EMC	$\sigma_E/E < 2.3\%/\sqrt{E}$
MUC	9 barrel + 8 endcap layers
Magnet	1 T Solenoidal

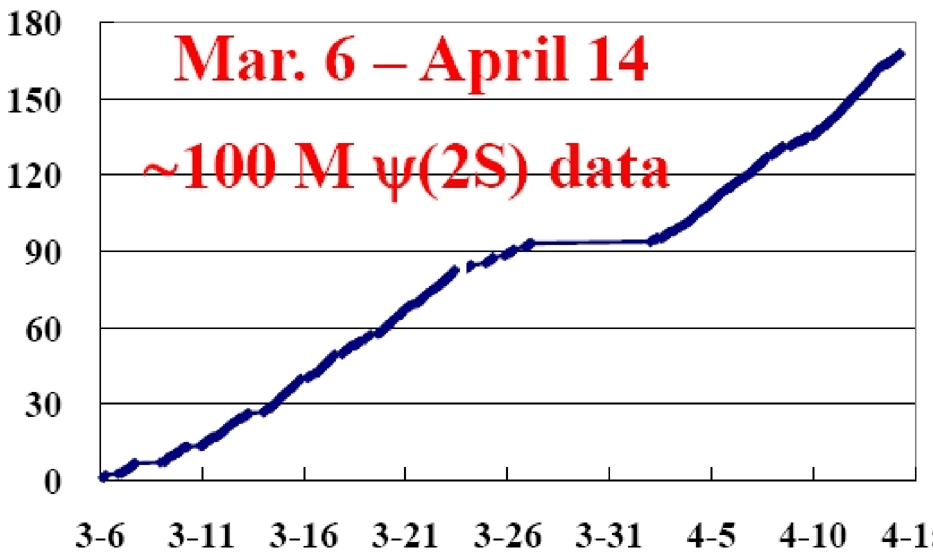
BESIII commissioning and data taking milestones

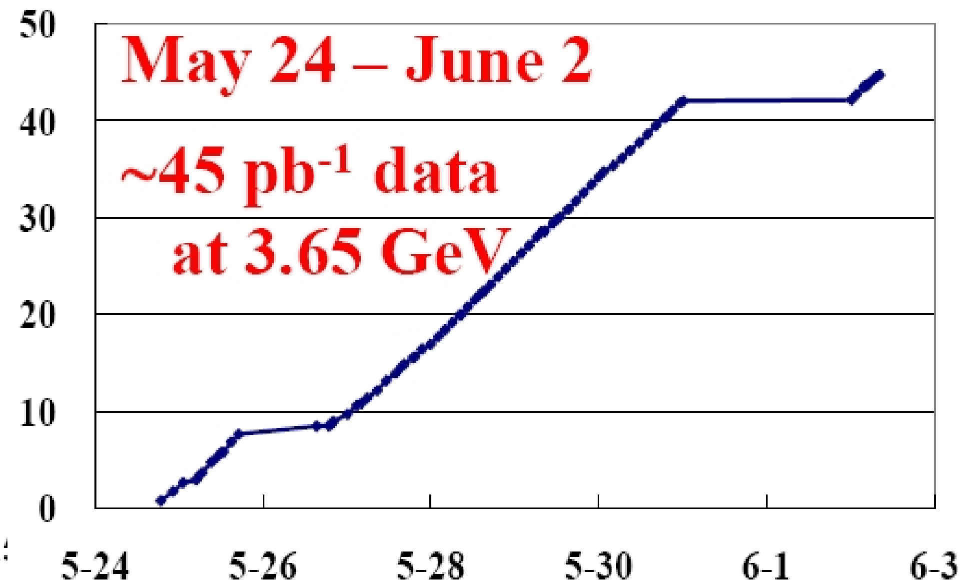
- **Mar 2008** — **first full cosmic-ray event**
- **April 30, 2008** — **move the BESIII to IP**
- **July 20 2008** — **first e^+e^- collision event in BESIII**
- **Nov. 2008** — **~ 14M $\psi(2S)$ events collected**
- **April 14, 2009** — **~ 100M $\psi(2S)$ events collected**
- **May 30, 2009** — **~ 42 pb^{-1} at continuum collected (3.65 GeV)**
- **July 28, 2009** — **~ 200M J/ψ events collected**

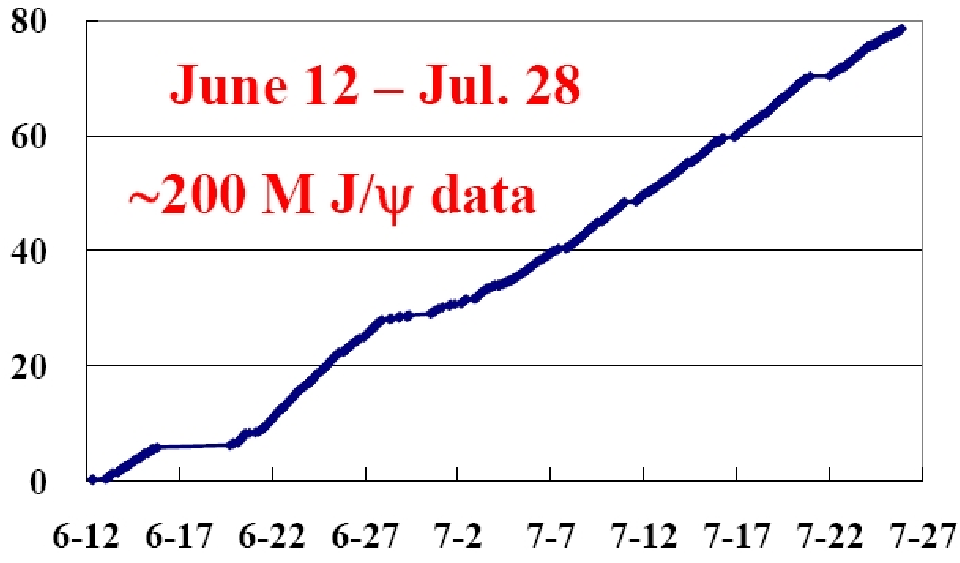
Peak luminosities

- **May 2009 at the $\Psi(2S)$ . . . . 3.3×10^{32} cm^{-2} s^{-1}**
- **July 2009 at the J/Ψ . . . . 0.7×10^{32} cm^{-2} s^{-1}**

BESIII commissioning and data taking milestones







Peak luminosities

- May 2009 at the $\Psi(2S)$
  . . . . . 3.3×10^{32} cm^{-2} s^{-1}
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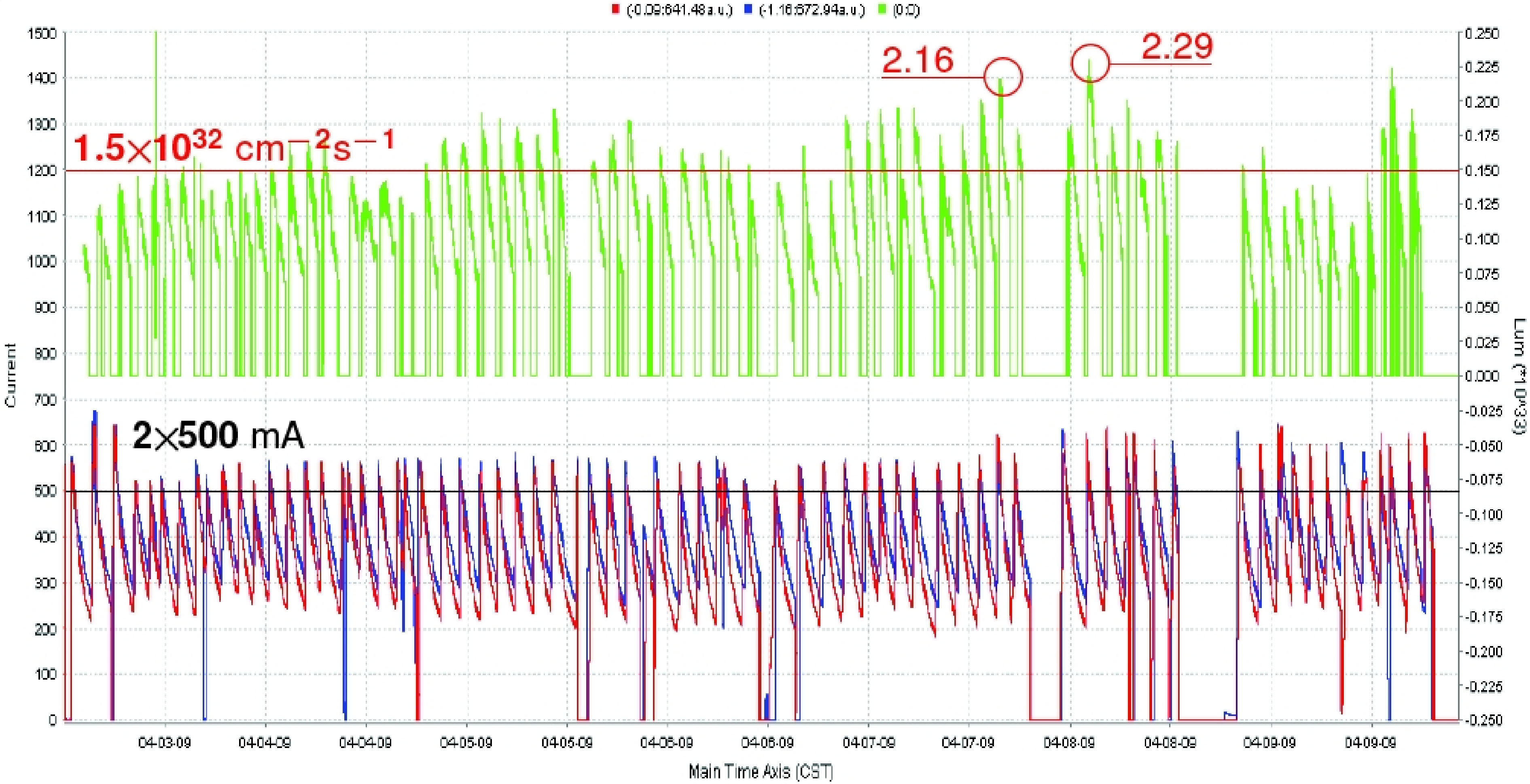
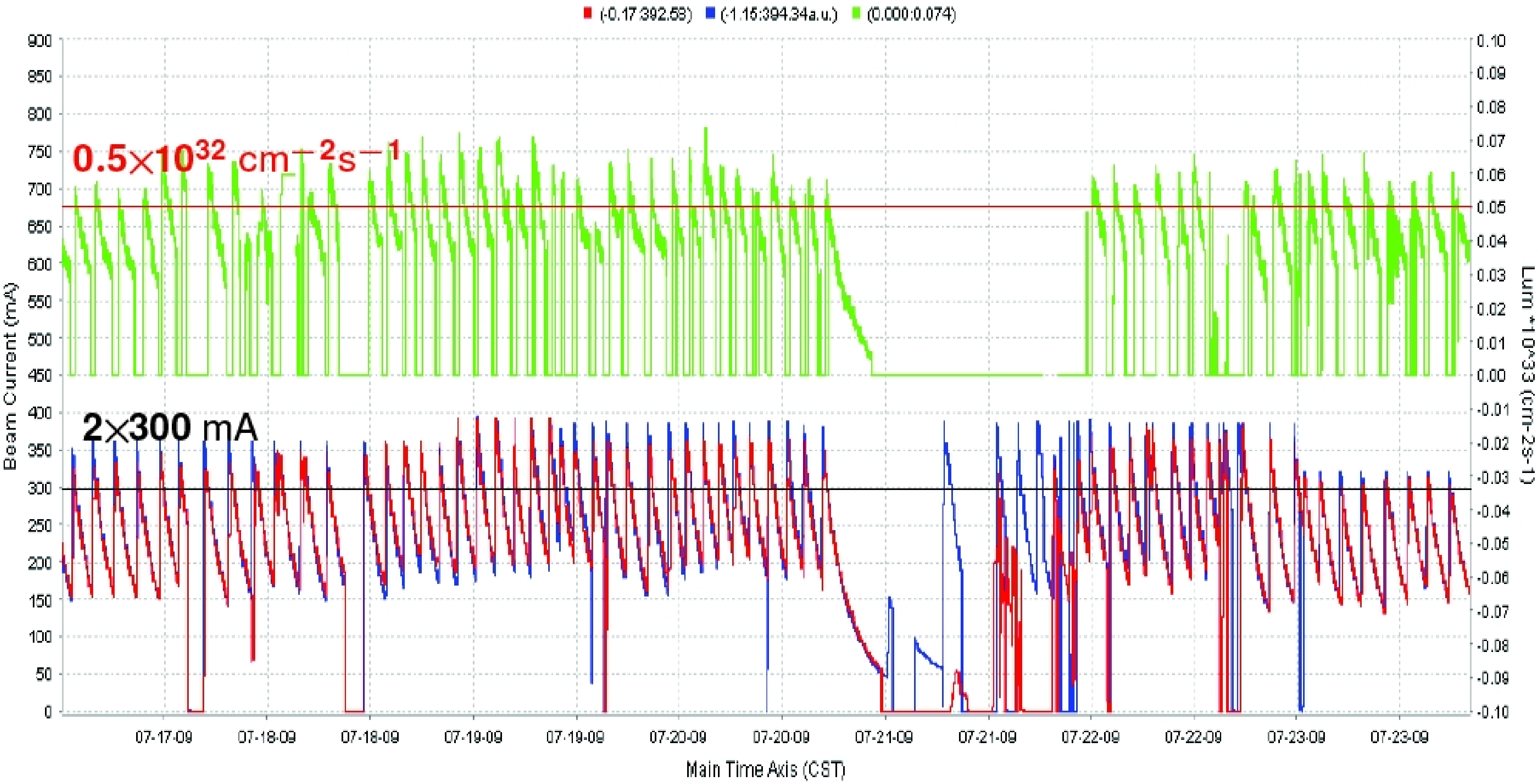
Ψ(2S) Run: Luminosity vs. Current



Machine is stable, with data taking rate 15 times higher than BEPC

The peak luminosity increases steadily meantime

J/Ψ Run: Luminosity vs. Current



Maximum collision beam current ~ 350 mA

Peak luminosity 0.5 – 0.7 × 10^{32} cm^{-2} s^{-1}

BESIII statistics @ designed peak luminosity (10^{33} $cm^{-2}s^{-1}$)

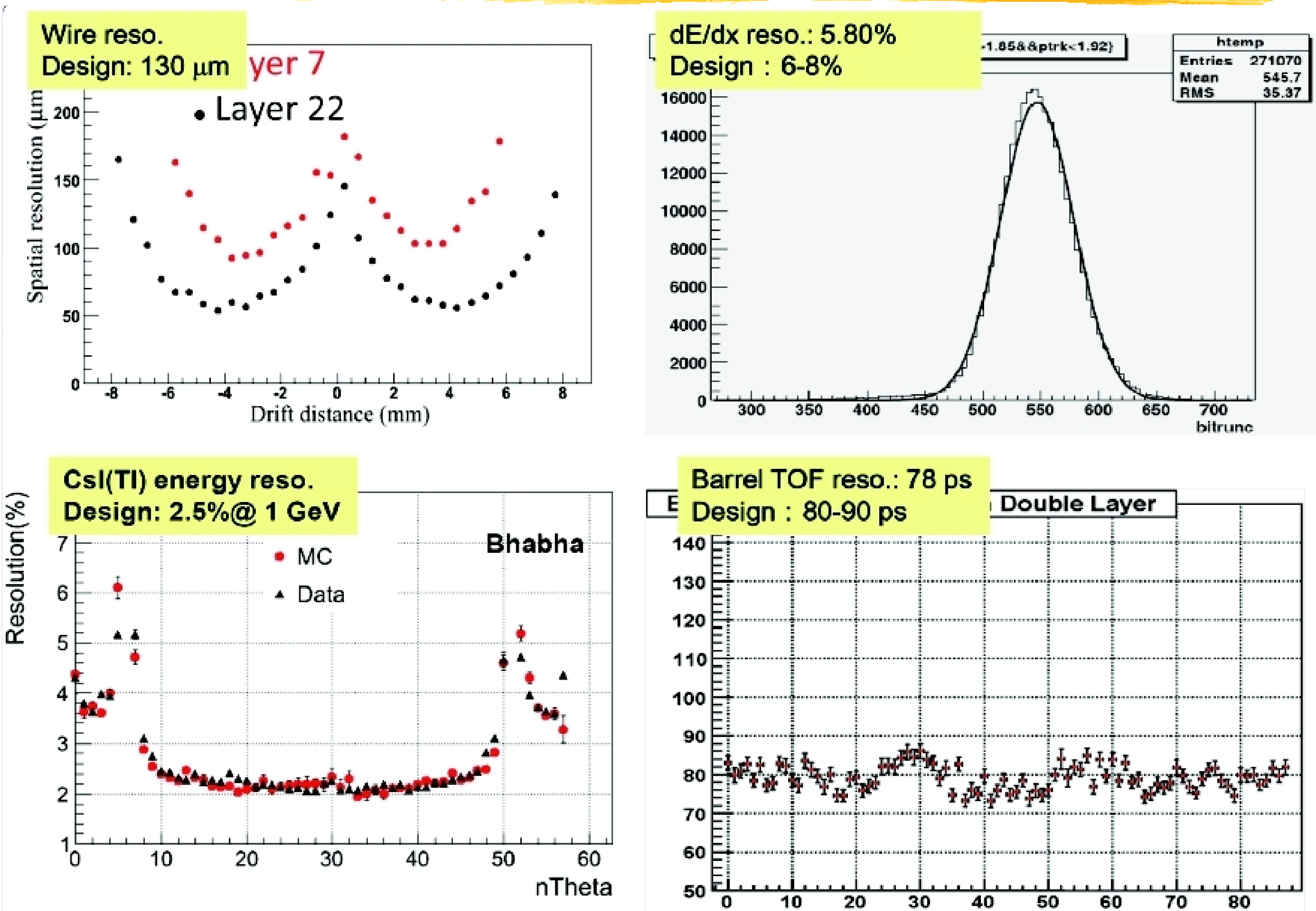
- R_{had} and precision test of Standard Model
- light hadron spectroscopy (Φf_0 (980), $\Phi\pi^0$,. . .)
- charm and charmonium physics
- τ physics
- precision measurements of CKM matrix elements
- search for new physics / new particles

Physics	Energy (GeV)	Peak Luminosity (10^{33} $cm^{-2}s^{-1}$)	Events/year	Existing data
J/ψ	3.097	0.6	10×10^9	60×10^6 (BESII)
τ	3.67(?)	1.0	12×10^6	--
ψ'	3.686	1.0	3×10^9	27×10^6 (CLEOc) 14×10^6 (BESII)
D	3.77	1.0	3×10^6	5×10^6 (CLEOc)
Ds	4.03	0.6	1×10^6	4×10^3 (BESI)
Ds	4.17	0.6	3×10^6	0.3×10^6 (CLEOc)
R scan	3.0-4.6	0.6(?)-1.0	--	--

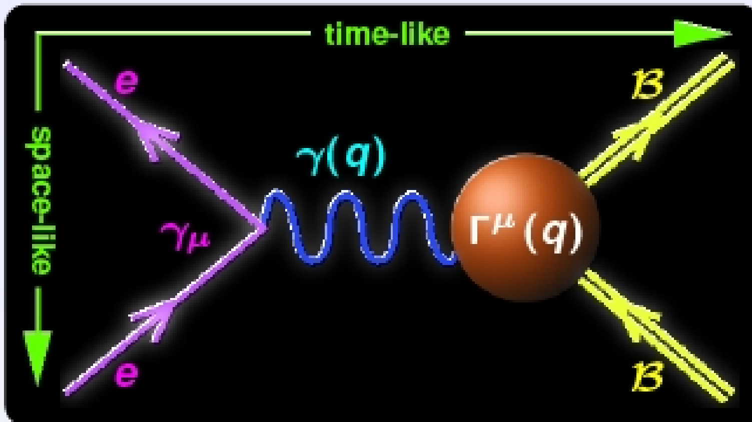
BESIII Physics Book - arXiv: hep-ex/0809.1869

10^7s data taking time each year

Detector performance and calibration



Nucleon form factors and cross sections

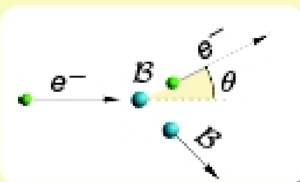


Nucleon current operator (Dirac & Pauli)

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

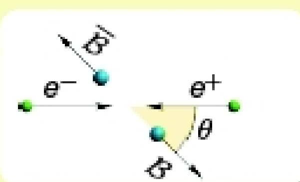
Electric and Magnetic Form Factors

$$G_E(q^2) = F_1(q^2) + \tau F_2(q^2) \qquad \tau = \frac{q^2}{4M_{\mathcal{B}}^2}$$
$$G_M(q^2) = F_1(q^2) + F_2(q^2)$$



Elastic scattering (Rosenbluth)

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2 E'_e \cos^2\frac{\theta}{2}}{4E_e^3\sin^4\frac{\theta}{2}}\left[G_E^2 - \tau\left(1+2(1-\tau)\tan^2\frac{\theta}{2}\right)G_M^2\right]\frac{1}{1-\tau}$$



Annihilation

Coulomb correction

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

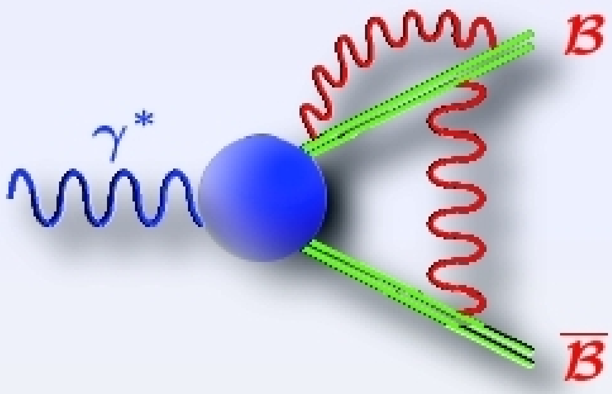
$$\beta = \sqrt{1-\frac{1}{\tau}}$$

Pointlike fermions e.g. $e^+e^- \to \mu^+\mu^-$: $\frac{d\sigma}{d\Omega} = \frac{\alpha^2\beta_\mu C}{4q^2}\left(2-\beta_\mu^2\sin^2\theta\right) \Longrightarrow |G_E| = |G_M| \equiv 1$

Courtesy of Simone Pacetti

The Coulomb Factor

Courtesy of Simone Pacetti



$p\bar{p}$ Coulomb interaction as FSI

[Sommerfeld, Sakharov, Schwinger, Fadin, Khoze]

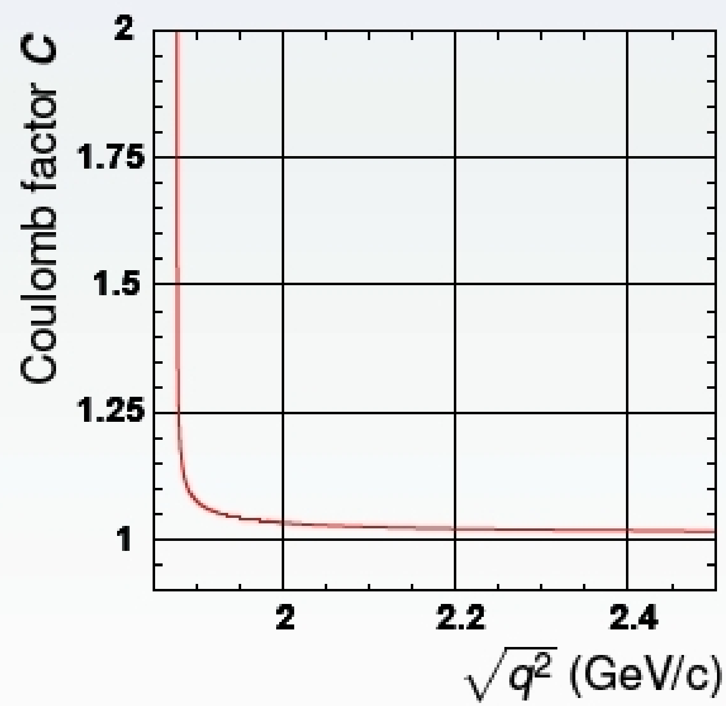
Distorted wave approximation

$$C = |\Psi_{\mathrm{Coul}}(0)|^2$$

S-wave: $$C = \frac{\frac{\pi\alpha}{\beta}}{1 - \exp\left(-\frac{\pi\alpha}{\beta}\right)} \xrightarrow[\beta\to 0]{} \frac{\pi\alpha}{\beta}$$

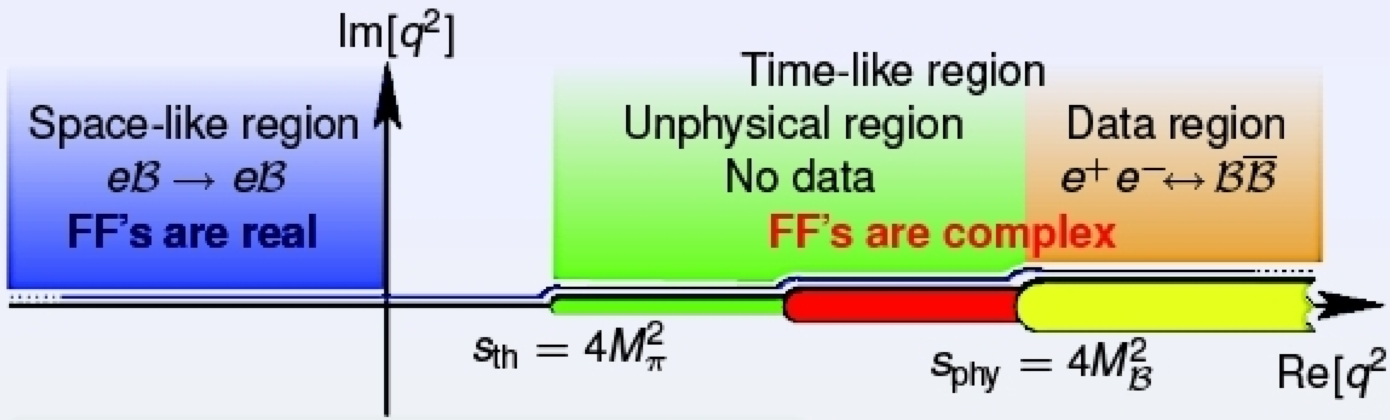
D-wave: $C = 1$

No Coulomb factor for boson pairs (P-wave)



Analyticity of baryon form factors

<u>q^2-complex plane</u>



Crossing: tot. helicity $= \begin{cases} 1 \Rightarrow G_E \\ 0 \Rightarrow G_M \end{cases}$

$$G_E(4M_\mathcal{B}^2) = G_M(4M_\mathcal{B}^2)$$

QCD counting rule constrains the asymptotic behaviour

Matveev, Muradyan, Tevkheldize, Brodsky, Farrar

Counting rule: $q^2 \to -\infty$
$i = 1$ Dirac, $i = 2$ Pauli FF

$$F_i(q^2) \propto (-q^2)^{-(i+1)} \Rightarrow G_{E,M} \propto (-q^2)^{-2}$$

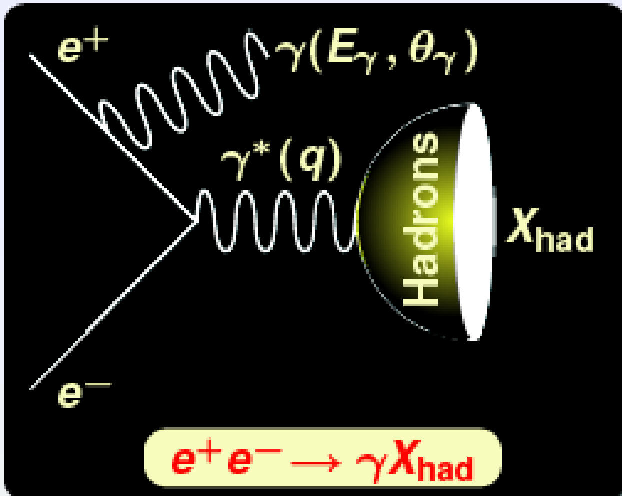
Analyticity: $q^2 \to \pm\infty$
(Phragmèn Lindelöf)

$$G_{E,M}(-\infty) = G_{E,M}(+\infty)$$

Courtesy of Simone Pacetti

Initial State Radiation

Courtesy of Simone Pacetti



- $$\frac{d^2\sigma}{dE_\gamma\, d\theta_\gamma} = W(E_\gamma, \theta_\gamma) \cdot \sigma_{e^+e^- \to X_{had}}(s)$$
- $$W(E_\gamma, \theta_\gamma) = \frac{\alpha}{\pi x}\left(\frac{2 - 2x + x^2}{\sin^2\theta_\gamma}\right)$$

- $s = q^2$, q .... X_{had} momentum
- E_γ, θ_γ ... CM γ energy, scatt. ang.
- E_{CM} .... CM e^+e^- energy
- $x = E_\gamma / 2E_{CM}$

Advantages

- All energies (q^2) at the same time

  $\Downarrow$

  Better control on systematics
  (e.g. greatly reduced point to point)
- Detected ISR $\Rightarrow$ full X_{had} angular coverage
- CM boost $\Rightarrow \begin{cases} \text{at threshold } \epsilon \neq 0 \\ \text{energy resolution } \sim 1 \text{ MeV} \end{cases}$

ISR: BESIII vs BABAR

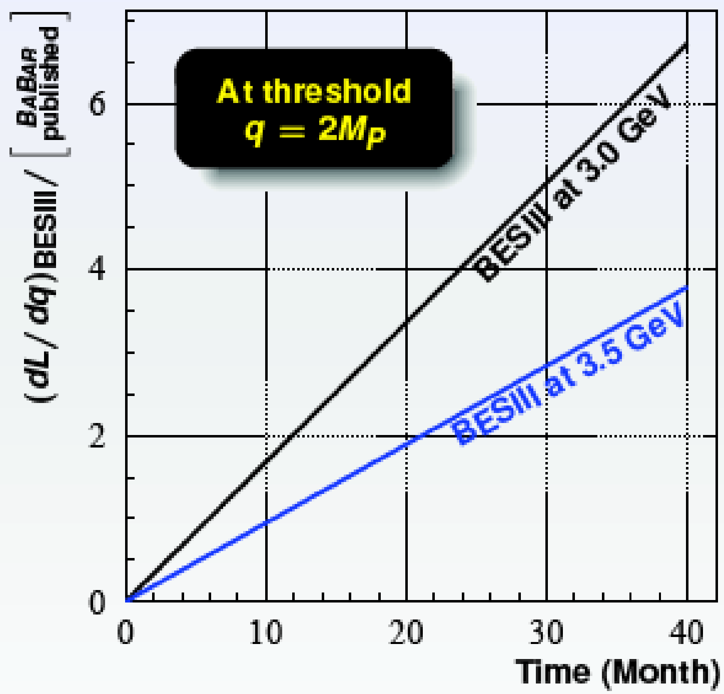
Courtesy of Simone Pacetti

ISR Luminosity

$$\frac{dL}{dq} = \frac{2q}{E_{\rm cm}^2} L_{ee} \int_{\cos\theta_\gamma^{\rm min}}^{\cos\theta_\gamma^{\rm max}} W(E_\gamma, \theta_\gamma)\, d\cos\theta_\gamma$$

L_{ee} .... total luminosity

$\theta_\gamma^{\rm min,\,max}$ ..... geom. accept.

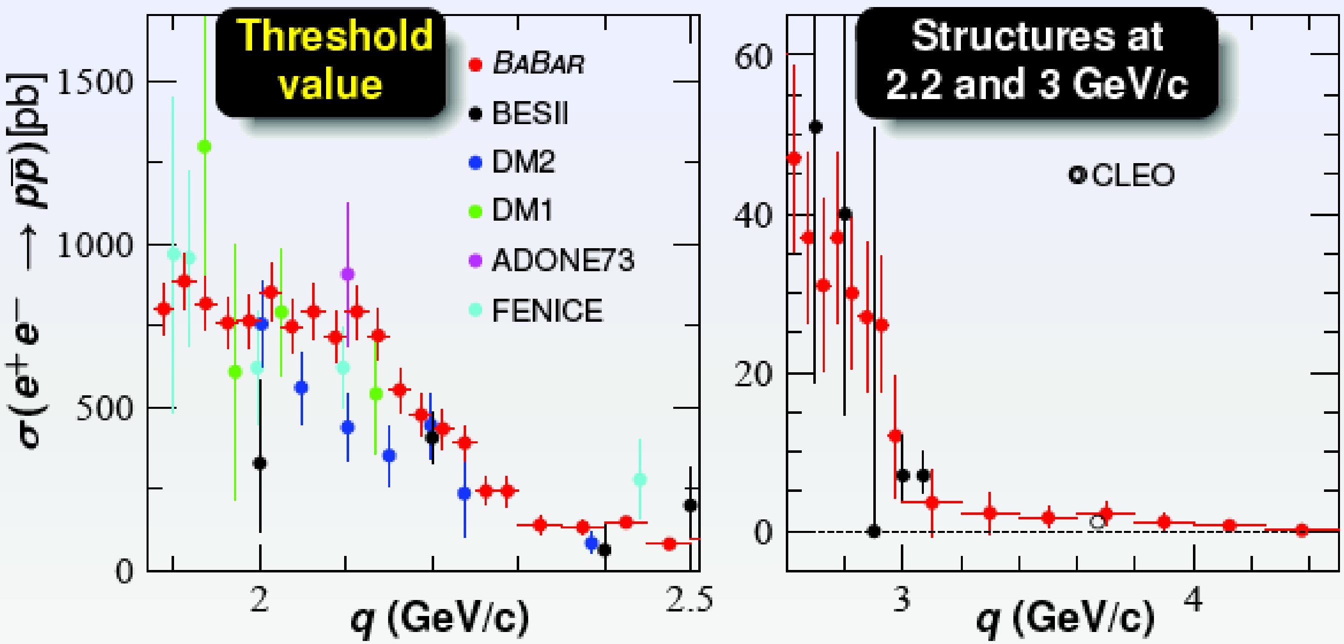


BESIII: lower CM energy ⇒ lower background ⇒ ISR γ detection + 0^o and No ISR γ detection ⇒ $\times$2.5 and $\times$5 in statistics

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

$$\sigma(e^+e^- \to p\bar{p}) = \frac{4\pi\alpha^2\beta_p C}{3q^2}\left[|G_M|^2 + \frac{2M_p^2}{q^2}|G_E|^2\right]$$

$$C \underset{\beta\to 0}{\sim} \frac{\pi\alpha}{\beta}$$



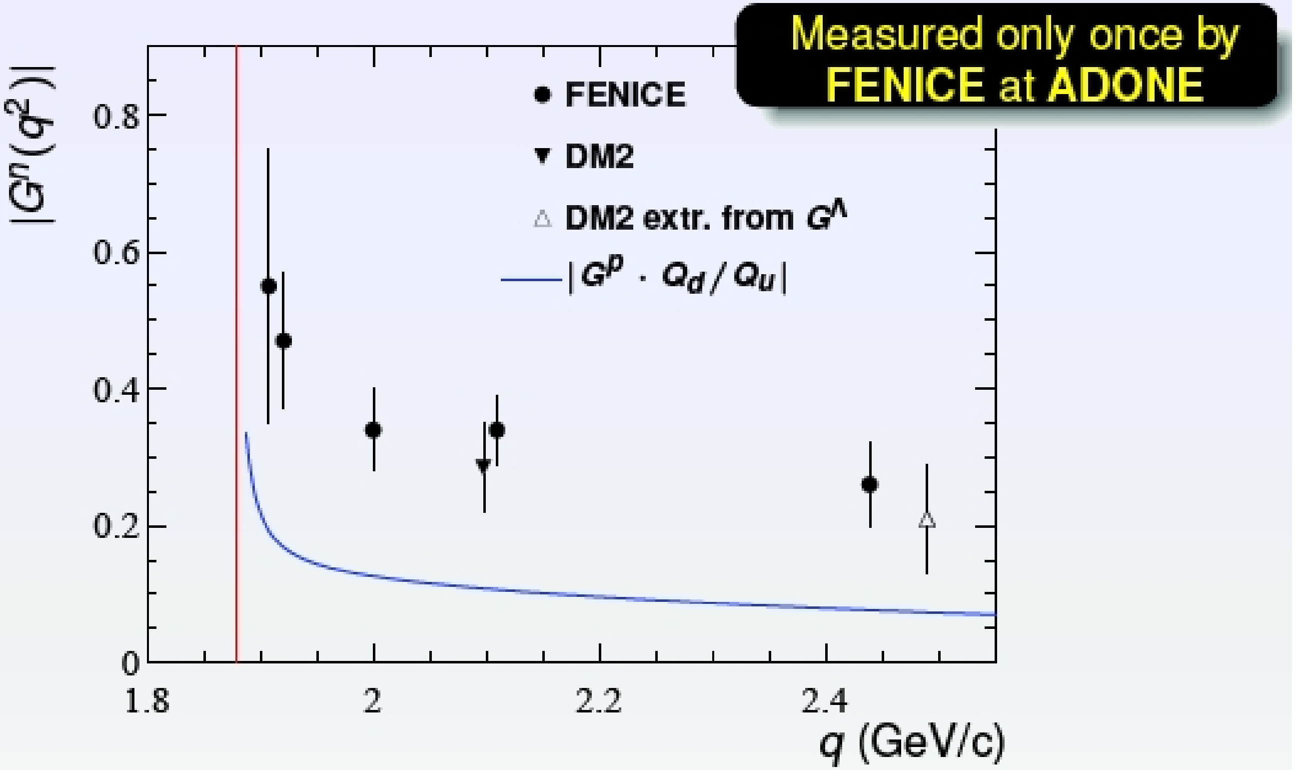
$$\sigma(e^+e^- \to p\bar{p})(4M_p^2) = \frac{\pi^2\alpha^3}{2M_p^2}\frac{\cancel{\beta_p}}{\cancel{\beta_p}}|G^p(4M_p^2)|^2 = 0.85\,|G^p(4M_p^2)|^2 \text{ nb}$$

$|G^p(4M_p^2)| \equiv 1$ as pointlike fermion pairs!

Courtesy of Simone Pacetti

R. Baldini et al., Eur. Phys. J. A 39 (2009) 315.

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

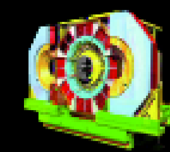


- $\int\mathcal{L} = 500\ \text{nb}^{-1}$ (15' at BESIII)
- About 100 candidates $n\bar{n}$ events!
- $\sigma(n\bar{n}) > \sigma(p\bar{p})$?
- Not zero at threshold?

Courtesy of Simone Pacetti

$e^+e^- \to n\overline{n}$ @ BESIII

Detection



- n, $\overline{n}$ detection efficiency and pattern by means of: $J/\Psi \to n(\overline{p}\pi^+)$ and $J/\Psi \to \overline{n}(p\pi^-)$ ($\geq 10^5$ events)
- TOF id (σ 100 ps, $D > 80$ cm) up to $E_{c.m.} \sim 3$ GeV
- Low-energy n detection: 10 cm scint. $\Rightarrow \epsilon_n^{\text{low}} = 10 - 20\%$
- High-energy n detection: calorimeter $\Rightarrow \epsilon_n^{\text{high}} \simeq 50\%$
- Antineutron detection: annihilation star $\Rightarrow \epsilon_{\overline{n}} \simeq 80\%$

First items

- $J/\Psi \to n\overline{n}$ (BR $\simeq 2 \cdot 10^{-3}$) .... $\geq 10^4$ events
- $\Psi(2S) \to n\overline{n}$ (BR $\simeq 3 \cdot 10^{-4}$) .... $\geq 10^3$ events

- $n\overline{n}$/day ($\mathcal{L} = 0.3 \times 10^{33}$ cm^{-2}s^{-1})$\sim$ 1000
- At threshold by means of ISR (boost)
- No way in ***BaBar*** and Belle

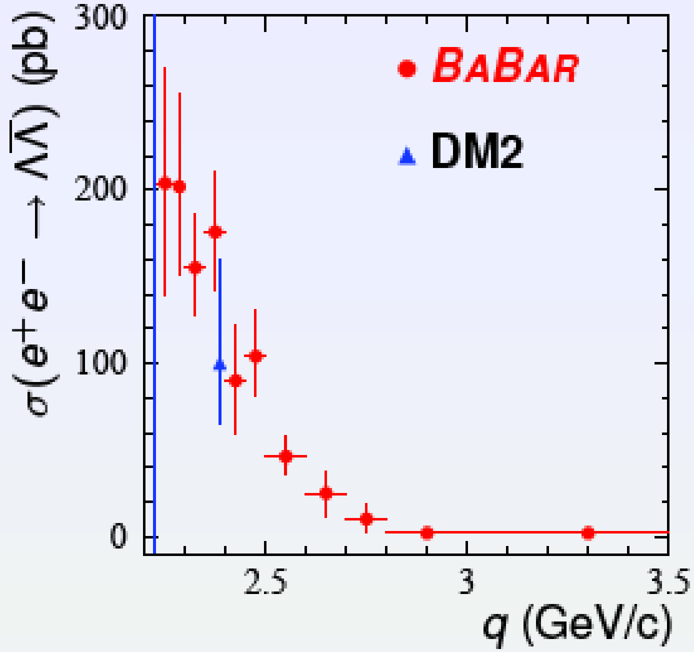
Courtesy of Simone Pacetti

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

Courtesy of Simone Pacetti

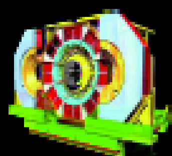
Measured only once by BaBar via ISR and DM2

Puzzling non-vanishing threshold value!



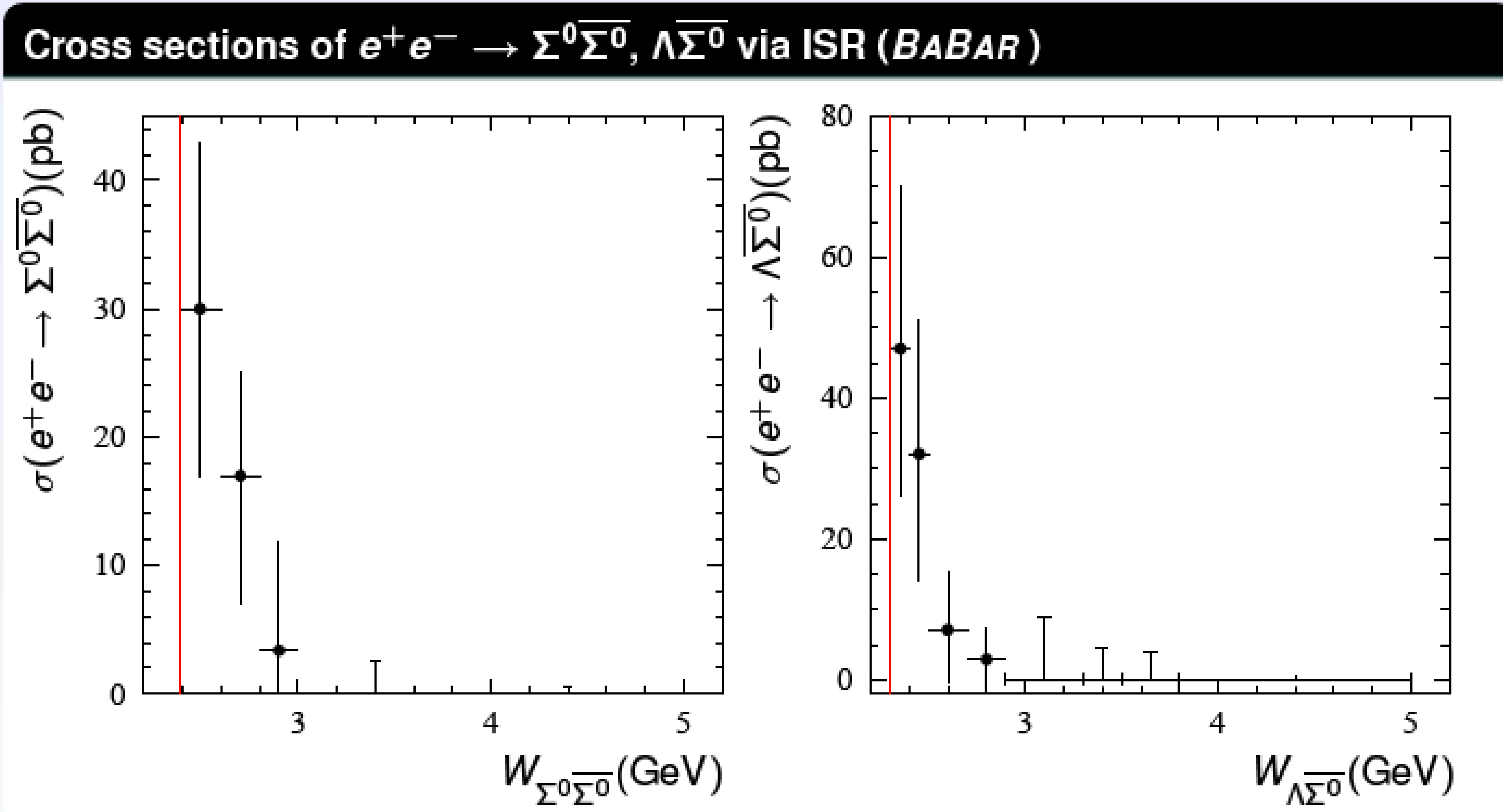
$e^+e^- \to \Lambda\overline{\Lambda}$ at BESIII

- If $B_{\mathrm{BESIII}} \to \frac{1}{2}B_{\mathrm{BESIII}} \Rightarrow \Lambda \to p\pi^-$ triggers direct measurement at threshold
- $\Lambda\overline{\Lambda}$/day ($\mathcal{L} = 0.3 \times 10^{33}\ \mathrm{cm^{-2}s^{-1}}$)$\sim 1000$
- If not: $\Lambda \to n\pi^0$ and $\overline{\Lambda} \to \overline{n}\pi^0$
- Λ polarization for free $\Rightarrow G_E^\Lambda$-G_M^Λ relative phase



$e^+e^- \to \Sigma^0\overline{\Sigma}^0$ and $e^+e^- \to \Lambda\overline{\Sigma}^0$

Courtesy of Simone Pacetti



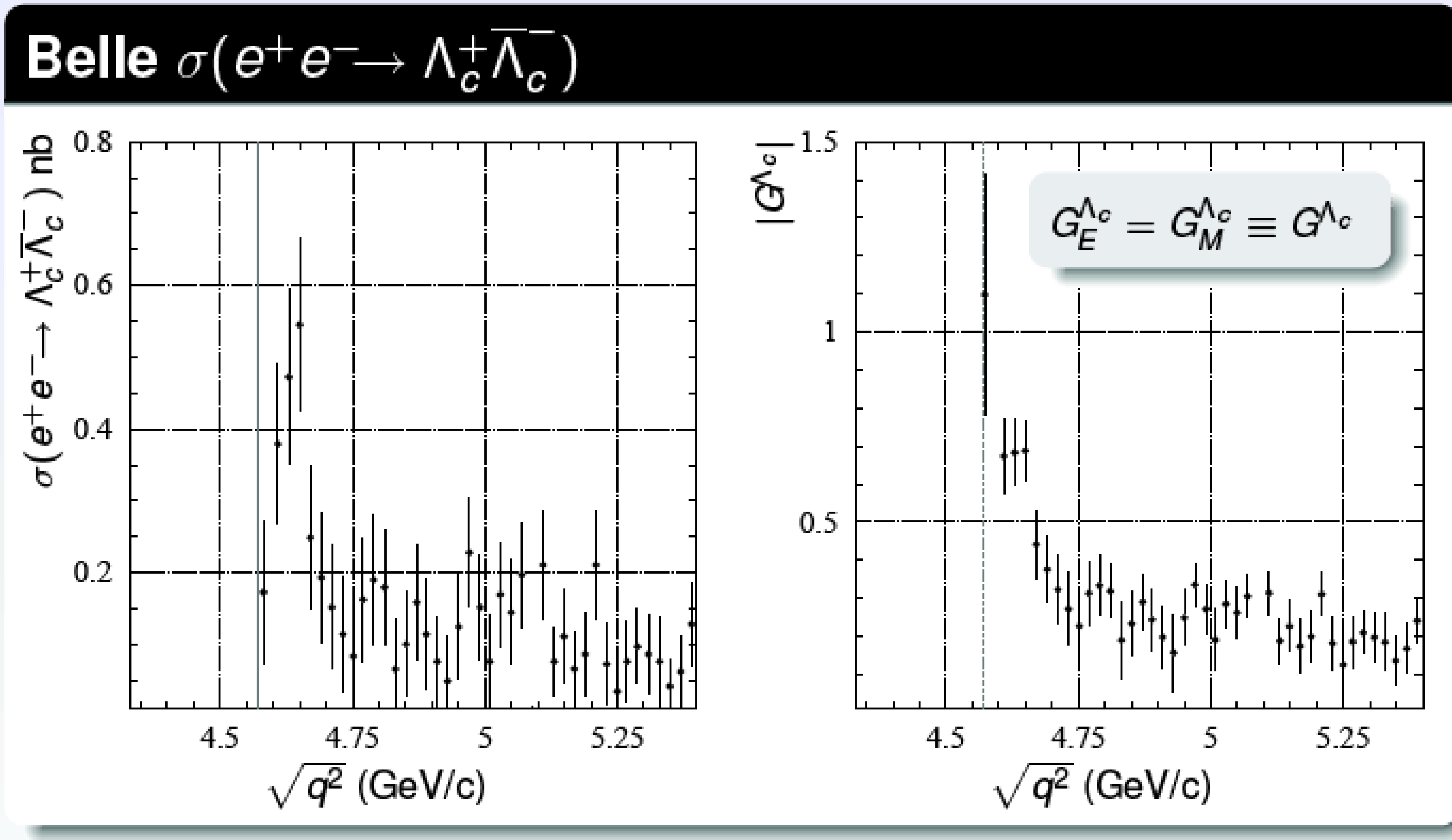
$\sigma(e^+e^- \to \Sigma^0\overline{\Sigma^0})_{th} = 30 \pm 13$ pb

$\sigma(e^+e^- \to \Lambda\overline{\Sigma^0})_{th} = 47 \pm 22$ pb

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

Λ_c^+ Form Factor

Courtesy of Simone Pacetti



$$|G^{\Lambda_c}(4M^2_{\Lambda_c})| = 1.1 \pm 0.3(\text{stat}) \pm 0.4(\text{syst})$$

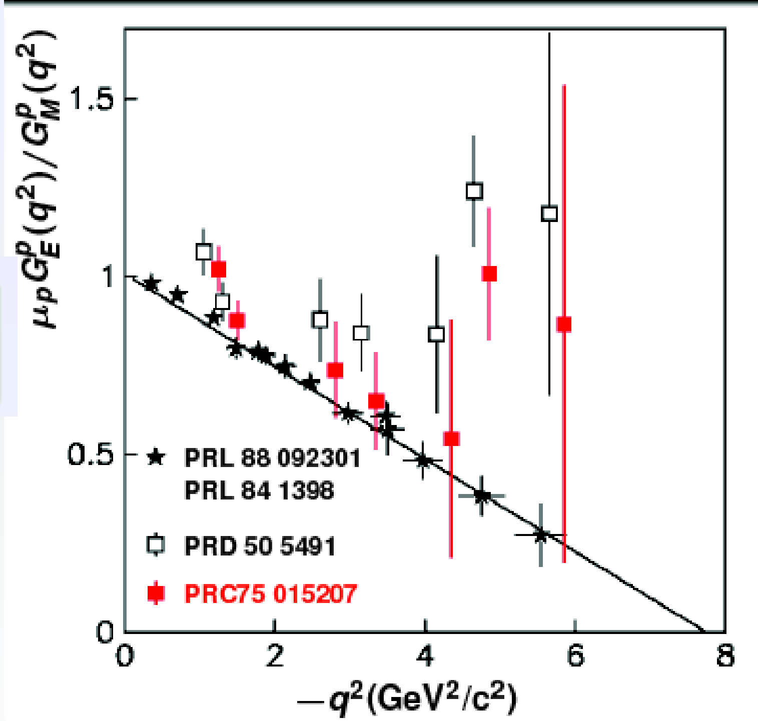
Accessible to BESIII

B. Aubert et al., Phys. Rev. D 73 (2006) 012005

Space-like G^p_E/G^p_M measurements

The ratio $R = \mu_p \frac{G_E^p}{G_M^p}$

Space-like data



$$G_E^p = F_1^p + \frac{q^2}{4M_p^2}F_2^p$$

$$G_M^p = F_1^p + F_2^p$$

Space-like

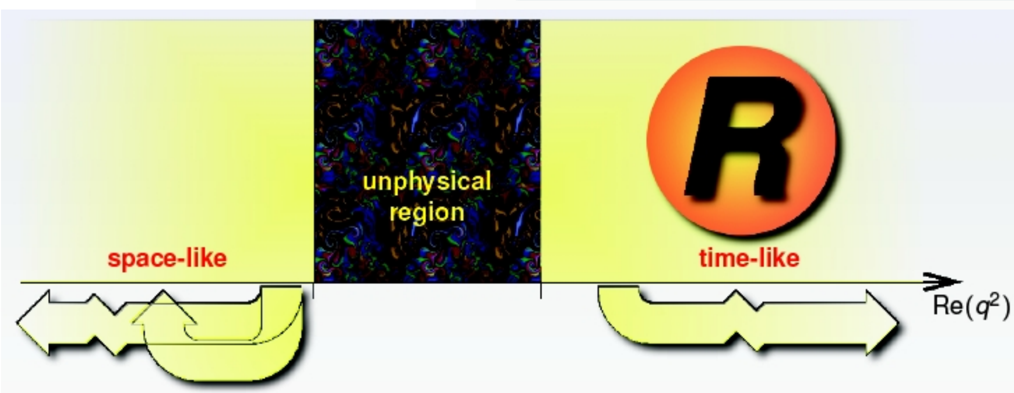
F_1 and $\frac{q^2}{4M_p^2}F_2$ cancellation

$$\frac{G_E^p(q^2)}{G_M^p(q^2)} < 1$$

Time-like

F_1 and $\frac{q^2}{4M_p^2}F_2$ enhancement

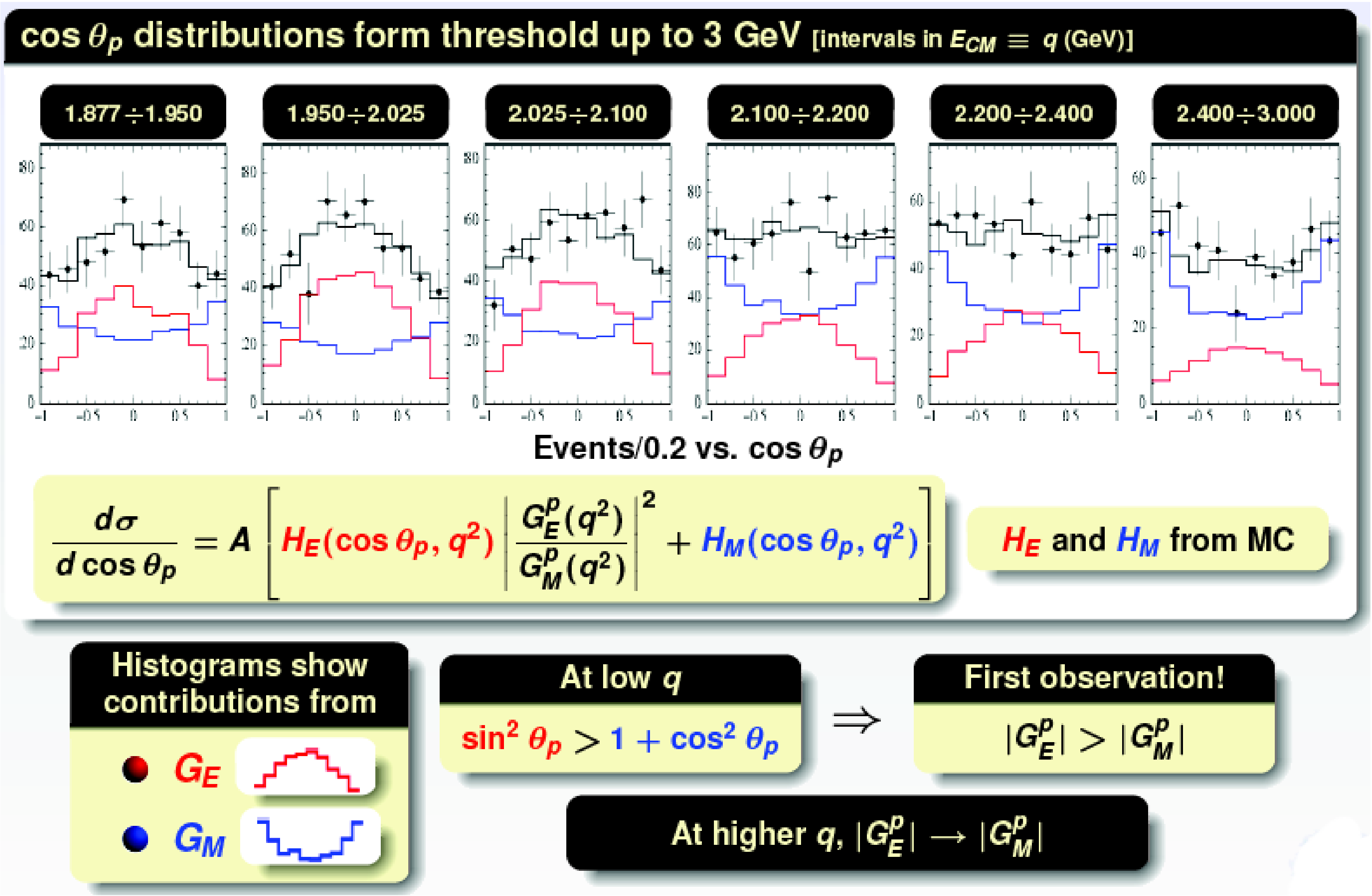
$$\left|\frac{G_E^p(q^2)}{G_M^p(q^2)}\right| > 1$$



Courtesy of Simone Pacetti

$e^+e^- \to p\bar{p}$ angular distribution (BABAR)

Courtesy of Simone Pacetti



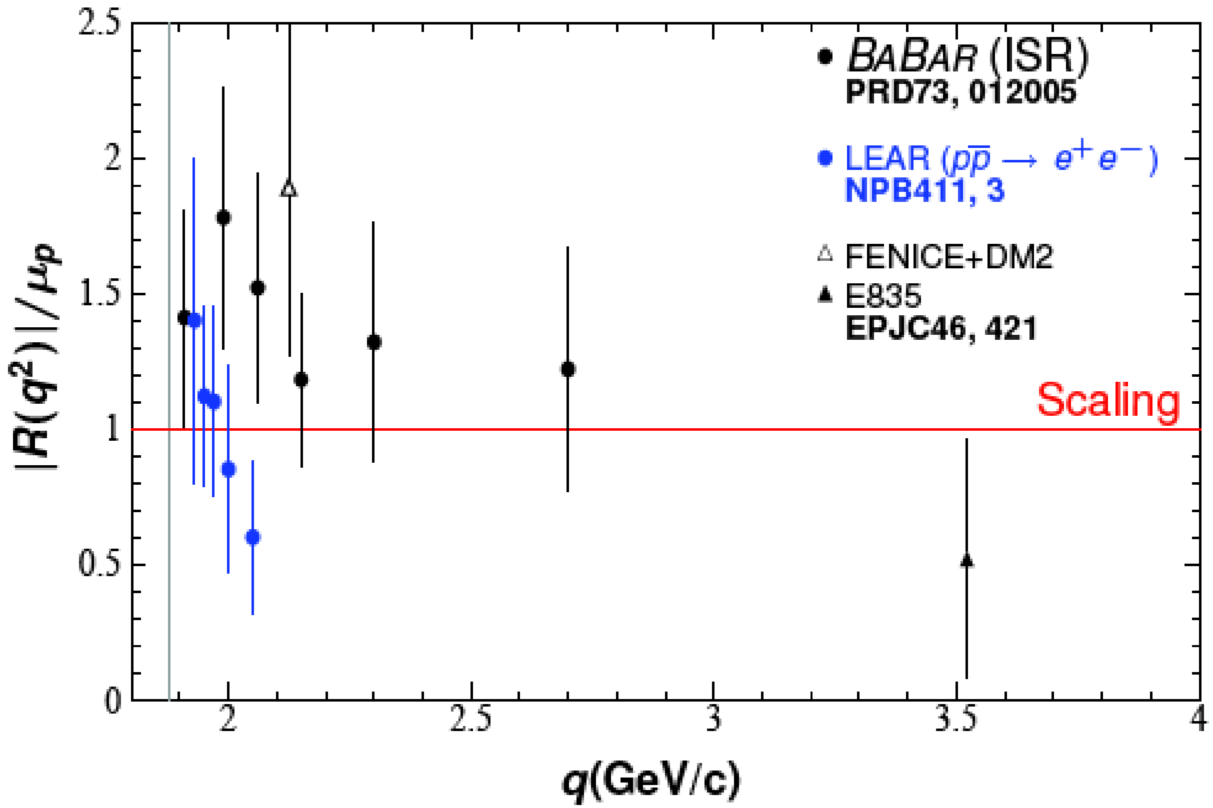
B. Aubert et al., Phys. Rew. D 73 (2006) 012005

Time-like $|G^p_E/G^p_M|$ measurements

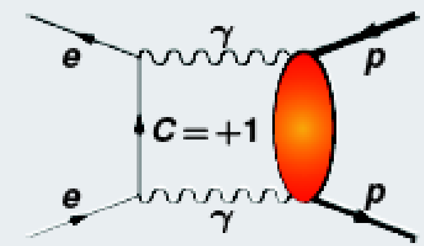
$$\frac{d\sigma}{d\cos\theta} = \frac{\pi\alpha^2\beta_p C}{2q^2}|G^p_M|^2\left[(1+\cos^2\theta)+\frac{4M_p^2}{q^2\mu_p^2}\sin^2\theta|R|^2\right]$$

$$R(q^2) = \mu_p\frac{G^p_E(q^2)}{G^p_M(q^2)}$$

Courtesy of Simone Pacetti



$\gamma\gamma$ exchange



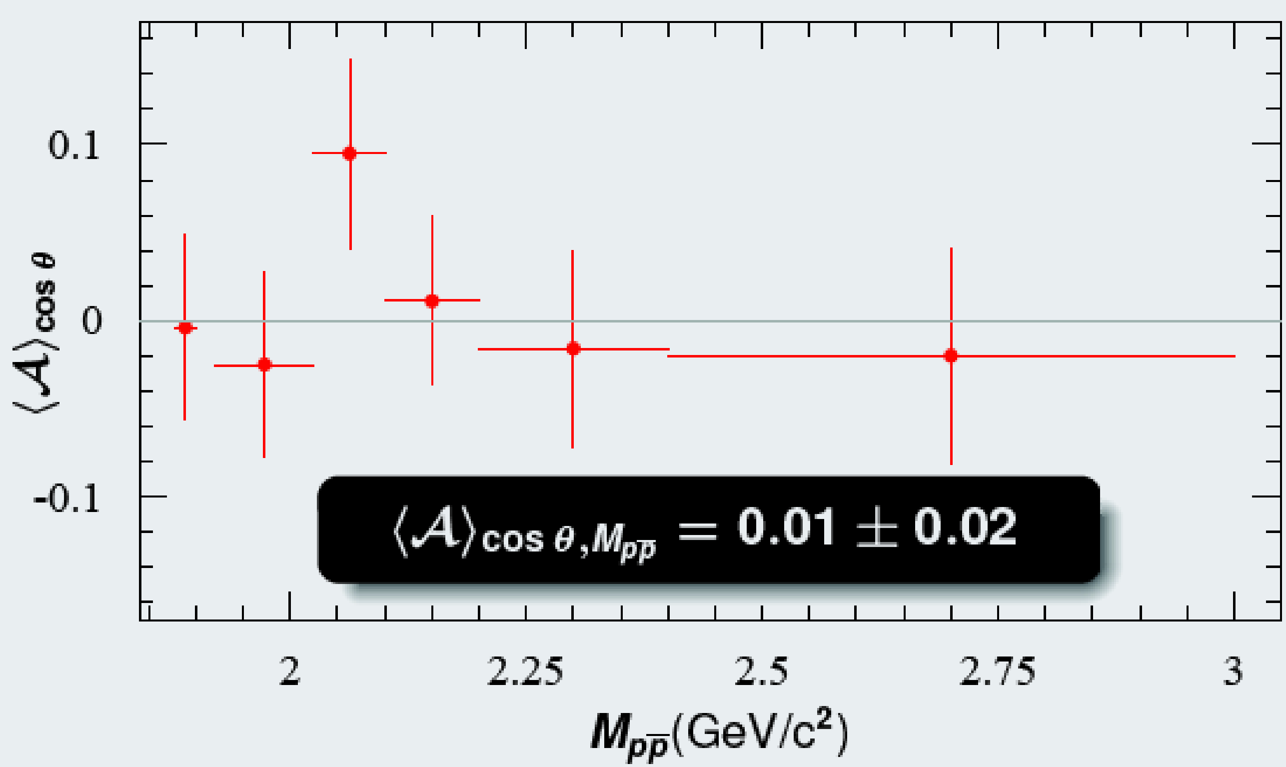
$\gamma\gamma$ exchange interferes with the Born term

Asymmetry in angular distributions

[PLB659, 197]

$\gamma\gamma$ exchange from $e^+e^- \to p\bar{p}\gamma$ BABAR data

$$\mathcal{A}(\cos\theta, M_{p\bar{p}}) = \frac{\frac{d\sigma}{d\Omega}(\cos\theta, M_{p\bar{p}}) - \frac{d\sigma}{d\Omega}(-\cos\theta, M_{p\bar{p}})}{\frac{d\sigma}{d\Omega}(\cos\theta, M_{p\bar{p}}) + \frac{d\sigma}{d\Omega}(-\cos\theta, M_{p\bar{p}})}$$

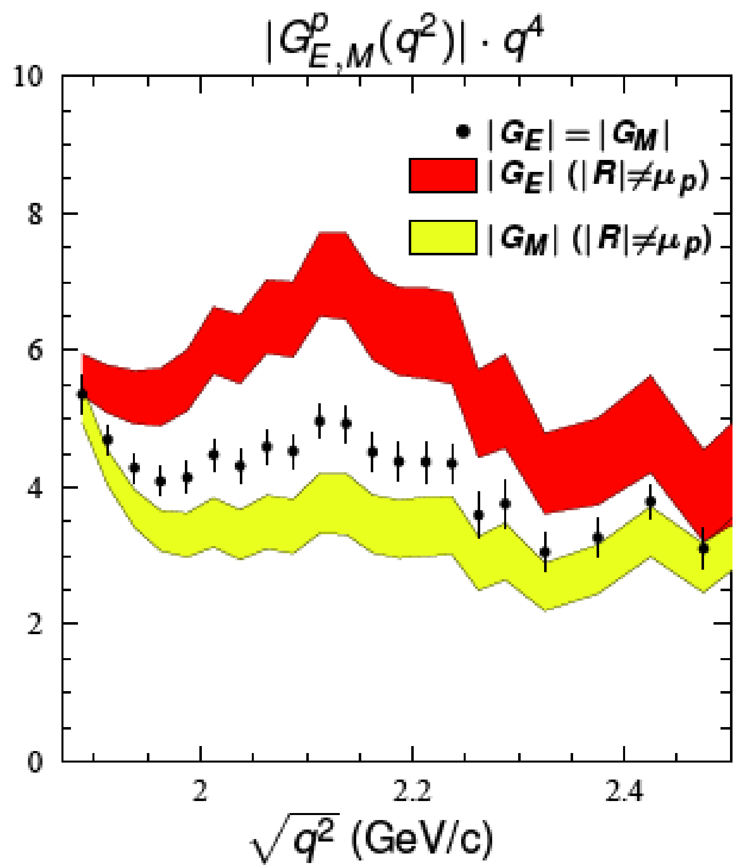


Courtesy of Simone Pacetti

E. Tomasi-Gustafsson et al., Phys. Lett. B 659 (2008) 197

$|G^p_E(q^2)|$ and $|G^p_M(q^2)|$ from $\sigma_{p\bar{p}}$ and DR

Courtesy of Simone Pacetti



$$|G_M(q^2)|^2 = \frac{\sigma_{p\bar{p}}(q^2)}{\frac{4\pi\alpha^2\beta C}{3s}} \left(1 + \frac{|R(q^2)|}{2\mu_p \tau}\right)^{-1}$$

- Usually what is extracted from the cross section $\sigma(e^+e^- \longrightarrow p\bar{p})$ is the effective time-like form factor $|G^p_{\text{eff}}|$ obtained assuming $|G^p_E| = |G^p_M|$ i.e. $|R| = \mu_p$
- Using DR's to parameterize R and the *BaBar* data on $\sigma(e^+e^- \leftrightarrow p\bar{p})$, $|G^p_E|$ and $|G^p_M|$ may be disentangled
- BESIII can measure separately $|G^p_E|$ and $|G^p_M|$

Summary

- An exciting scenario allow for the investigation of Form Factors @ BESIII:
- Possible data taking plans:
  - $e^+e^- \longrightarrow p\overline{p}$
  - $e^+e^- \longrightarrow n\overline{n}$
  - $e^+e^- \longrightarrow \Lambda\overline{\Lambda}$
  - $e^+e^- \longrightarrow \Sigma^0\overline{\Sigma}^0$
  - $e^+e^- \longrightarrow \Lambda\overline{\Sigma}^0$
  - $e^+e^- \longrightarrow \Lambda^+_c\overline{\Lambda}^-_c$
  - Time-like $|G^p_E/G^p_M|$, $|G^p_E|$ and $|G^p_E|$

- Investigation performed @ unprecedented luminosities:
  - $\Psi(2S)$: achieved $L = 3.3 \times 10^{32}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$
  - J/Ψ: achieved $L = 0.7 \times 10^{32}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$

- Investigation performed in a wide energy range:
  - $\sqrt{s}_{max} = 2 - 4.6\ \ \mathrm{GeV}.$

Back-up slides

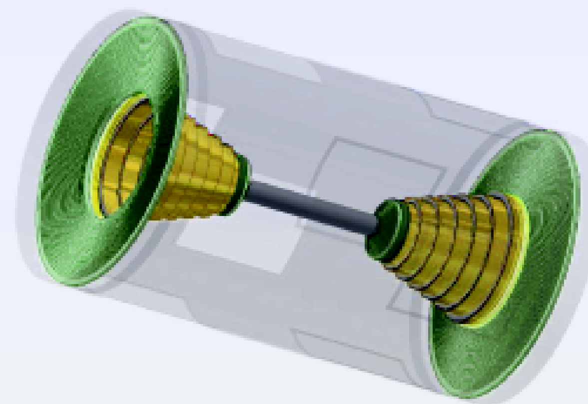
Thank you!

BESIII main features

Courtesy of Simone Pacetti

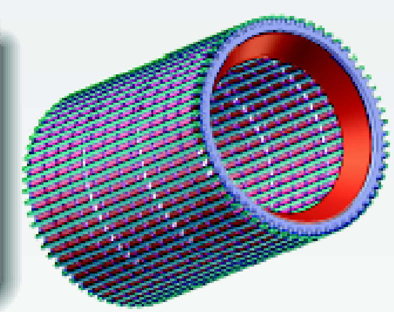
Drift Chamnber

- Low gas misture (60% He, 40% Propane)
- Carbon filter cylindres: $R_{\rm in} = 6.3$ cm, $T_{\rm in} = 1$ mm,
  $R_{\rm out} = 81$ cm $T_{\rm out} = 1$ cm
- 6 Al stepped flanges: T = 1.8 cm
- 43 layers: 7000 25 μm gold-plated sense wires,
  22000 Al field-shaping wires
- $\sigma_{x,y} \sim 130\ \mu$m, $\sigma(De/dx) \sim 6\%$



CsI Calorimeter

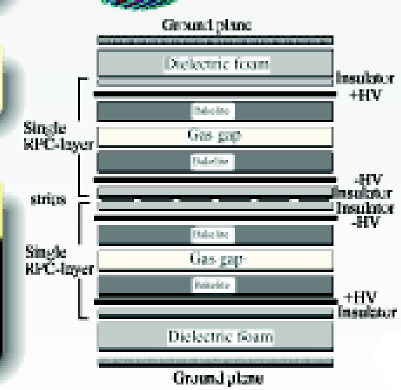
- 6240 CsI(Tl): 5280 Barrel, 960 Endcaps, 13000 photodiodes
- 28×5.2^2 cm^3
- $\Delta E/E \sim 2.5\%$ at 1 GeV, noise ~ 220 keV



Superconducting Magnet: 1 T

RPC μ Chambers

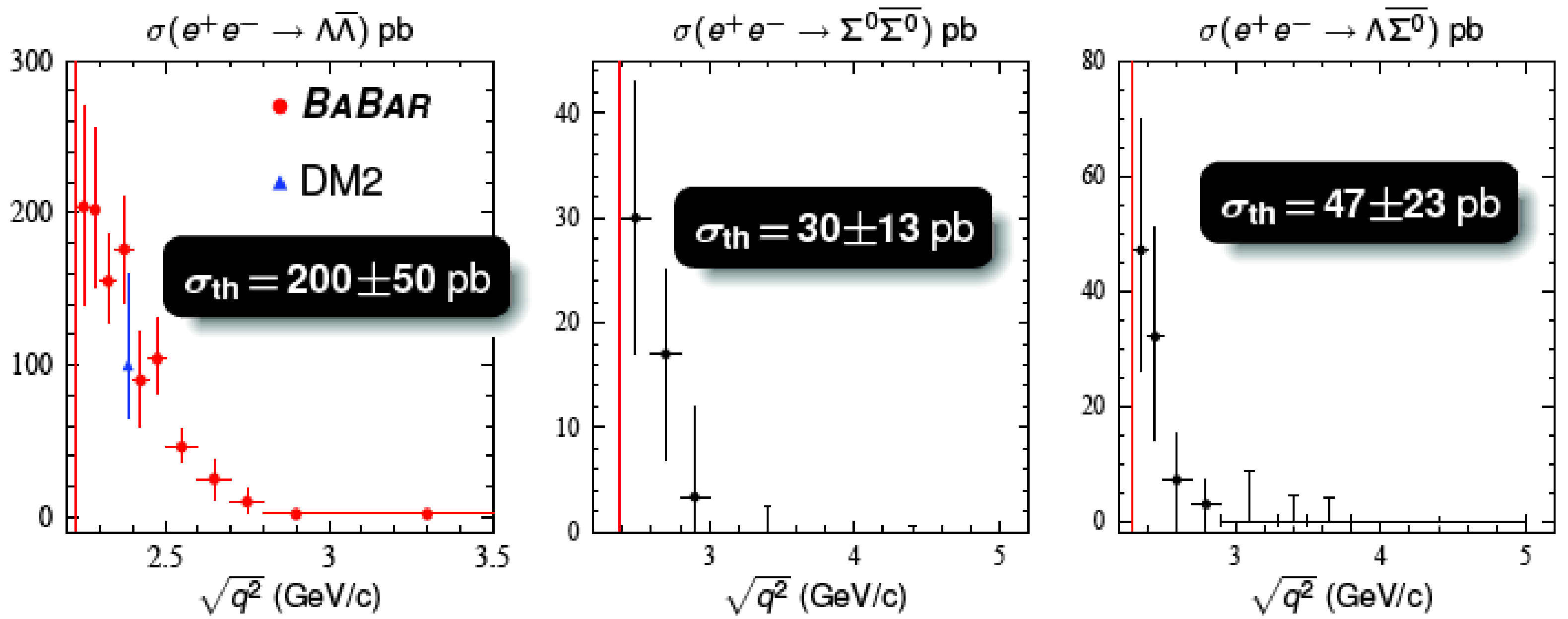
9/8 layers Barrel/Endcaps, Strip x, y 4cm
Plastic foil instead linseed oil: noise ~ 0.1 Hz/cm^2, $\epsilon \sim 95\%$



Neutral Baryons puzzle (BABAR)

$$\sigma(e^+e^- \to \mathcal{B}^0\overline{\mathcal{B}}^0) = \frac{4\pi\alpha^2\beta C_0}{3q^2}\left[|G_M^{\mathcal{B}^0}|^2 + \frac{2M_{\mathcal{B}^0}^2}{q^2}|G_E^{\mathcal{B}^0}|^2\right] \xrightarrow[q\to 2M_{\mathcal{B}^0}]{} \frac{\pi\alpha^2\beta}{2M_{\mathcal{B}^0}^2}|G^{\mathcal{B}^0}|^2 \to 0$$

No Coulomb correction at hadron level: $C_0 = 1$



Remnant of Coulomb interactions at quark level? $\Rightarrow$ $C_0 \propto \beta^{-1}$ as $q \to 2M_{\mathcal{B}^0}$ $\Rightarrow$ For any neutral baryon

$$\sqrt{\sigma_{\mathcal{B}^0\overline{\mathcal{B}}^0}} \propto \frac{|G^{\mathcal{B}^0}|}{M_{\mathcal{B}^0}}$$

Courtesy of Simone Pacetti

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