The timelike electromagnetic form factors of proton and charged kaon at high energies

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OUTLINE

1. **Proton FF description**
2. **Babar detector, ISR method**
3. **Proton FF data**

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4. **Charged kaon FF description**
5. **Kaon FF data**

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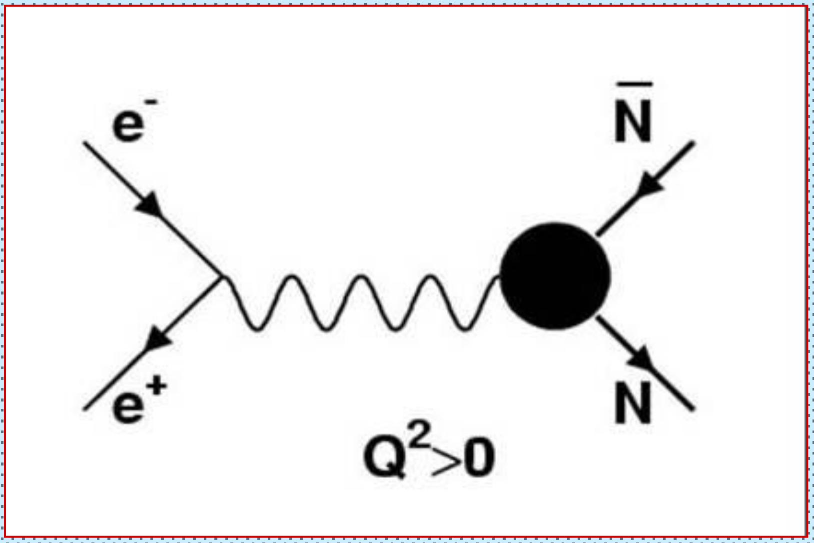
6. **Conclusion**

$p\bar{p}$ quantum numbers



$J^{PC} = 1^{--}$, $J = L+S$,
$P=(-1)^{L+1}=-1$, $L=0,2$,
$C=(-1)^{L+S}=-1$, $S=1$,

S, D – waves,

two form factors
e.g. G_E , G_M

$e^+e^- \to N\bar{N}$ cross section

Differential cross section (N=p,n) :

$$\sigma(e^+e^- \to N\bar{N}) = \frac{\alpha^2\beta C^2}{4m^2}\left(|G_M|^2(1+\cos^2\theta) + \frac{4m_B^2}{m^2}|G_E|^2(1-\cos^2\theta)\right)$$

Total cross section:

$$\sigma(e^+e^- \to N\bar{N}) = \frac{4\pi\alpha^2\beta C}{3m^2}\left(|G_M|^2 + \frac{2m_B^2}{m^2}|G_E|^2\right)$$

Effective form factor

$$|F|^2 = \frac{|G_M|^2 + |G_E|^2/2\tau}{1+1/2\tau}, \quad \tau = \frac{m^2}{4m_B^2}$$

Two measurable values:
1 - effective FF,
2 - $|G_E/G_M|$

C for protons : $C = y/(1-e^{-y}),\ y = \pi\alpha/\beta,\ \alpha = 1/137,\ \beta = v/c$

Function C (Coulomb factor) is significant at ~ 1 MeV above threshold

Expectations for the nucleon form factors

-- $|G_E|=|G_M|$ at threshold, S-wave only

-- σ -> const at threshold, C ~ 1/v

-- proton polarization ~ $\phi(G_E-G_M)$

perturbative QCD constrains the FF asymptotic behavior

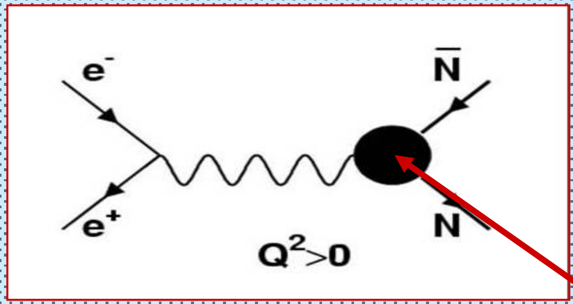
$$q^2 \to -\infty \Rightarrow G_{E,M} \to \frac{\text{constant}}{q^4 \ln\left(q^2/\Lambda^2_{QCD}\right)^2}$$

pQCD + analyticity

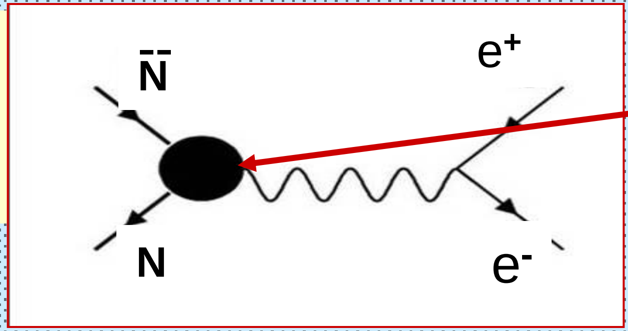
$$q^2 \to \pm\infty \Rightarrow G_{E,M}(q^2) = G_{E,M}(-q^2)$$

Reactions to study e.m. TL form factors

1. e^+e^- annihilation,
e+e- colliders - Adone,DCI, CLEO, BES, VEPP-2000

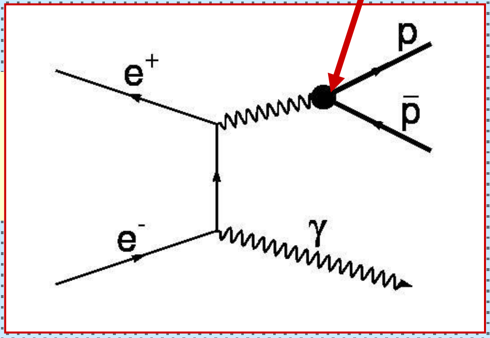


2. Antiproton annihilation,
proton-antiproton colliders – CERN, FNAL



Form factor

3. ISR – Initial State Radiation,
e+e- colliders - Babar



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

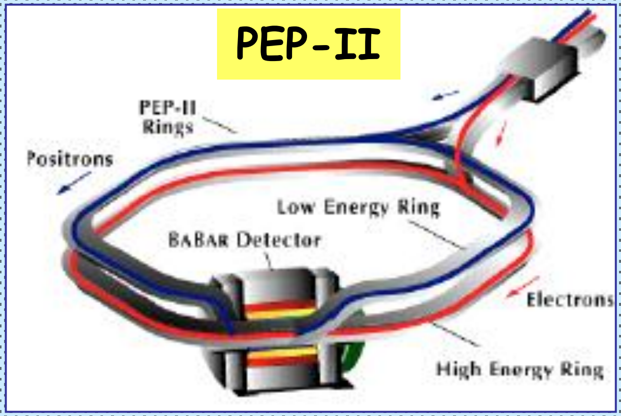
Two latest BABAR works:

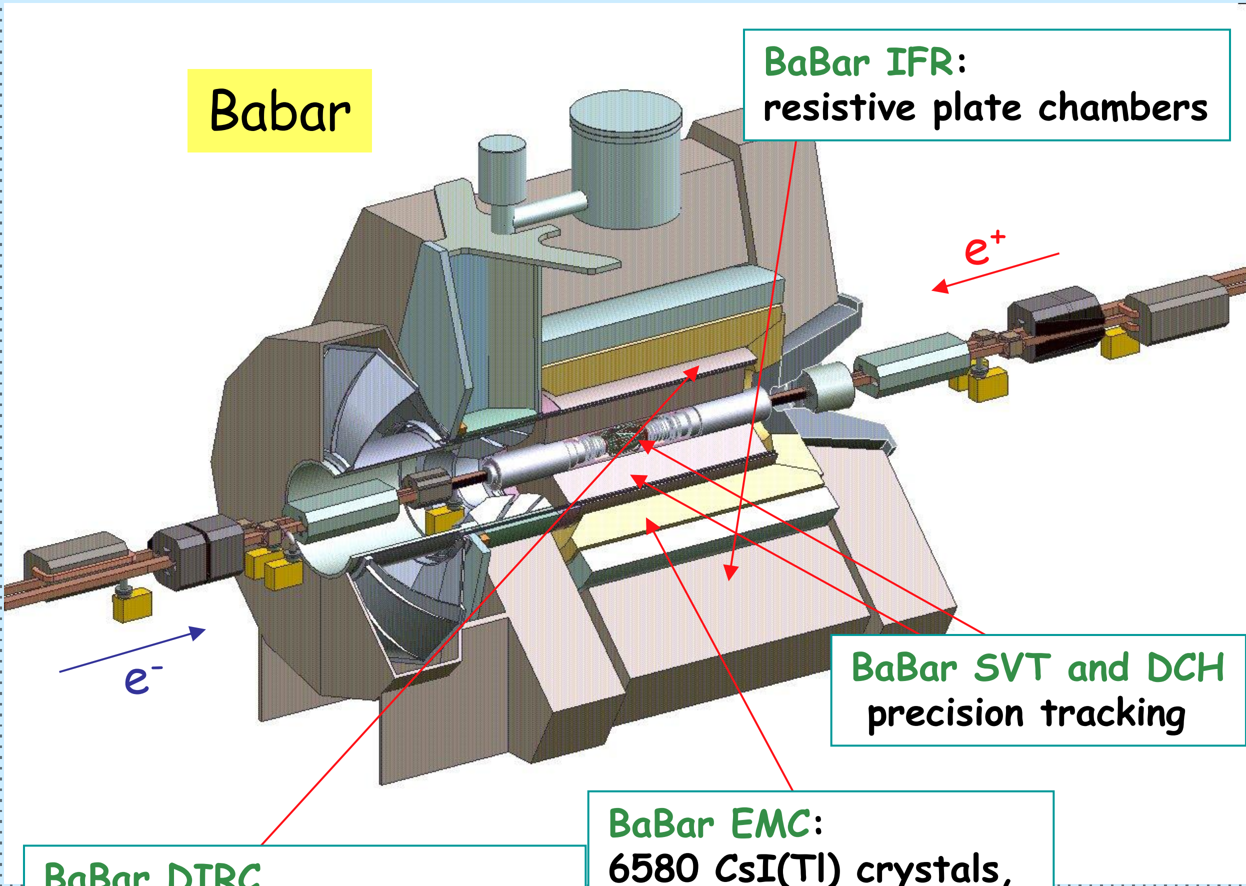
1 - **PhysRevD.87.092005(2013), m < 4 GeV - LA ISR**

2 - **PhysRevD.88.072009(2013), m =3 – 6 GeV - SA ISR**

PEP-II e+e- collider, Babar detector

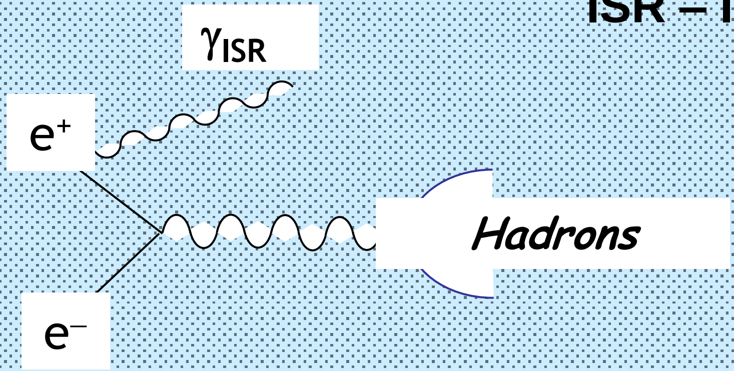
E_+ = 3.1 GeV, E_- = 9 GeV





E_{CM} = M(ϒ(4S))=10.6 GeV
2000 - 2008 yrs
L_{ins}=10 nb^{-1}/sec
IL = 500 fb^{-1}
N(B) = 10^9

e+e→hadrons in ISR



$M_{hadr} < \sqrt{s}$

ISR – Initial State Radiation or Radiative Return

$$\frac{d\sigma(s,x)}{dx\,d(\cos\theta)} = H(s,x,\theta)\cdot\ \sigma_0\big(s(1-x)\big)$$

***H* - radiation function**

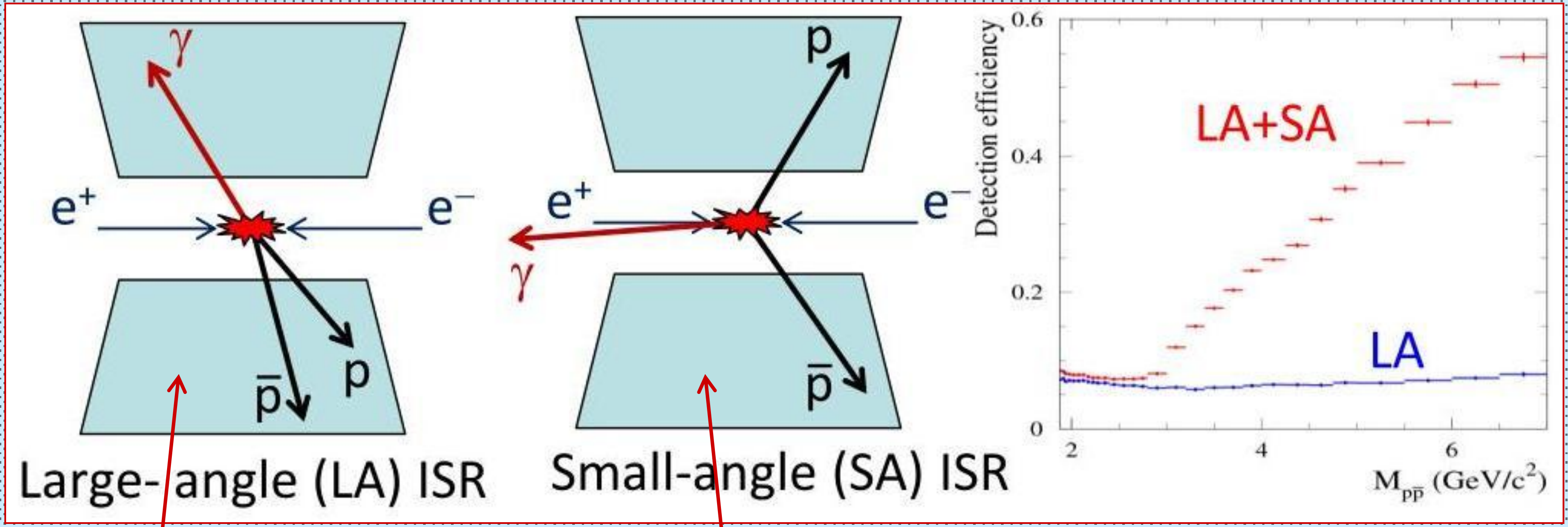
$$H(s,x,\theta) = \frac{\alpha}{\pi x}\left(\frac{2-2x+x^2}{\sin^2\theta} - \frac{x^2}{2}\right),\quad x = \frac{2E_\gamma}{\sqrt{s}}$$

$L_{ISR} \sim 0.3\%\ L_0$,
with $L_0 \sim 0.5\ ab^{-1}$ ---> $L_{ISR} \sim 1.5\ fb^{-1}$!

Advantages of ISR

1. Full energy range from $2m_\pi$ up to $\sqrt{s}$ is available
2. Detection efficiency is independent on the reaction mechanism
3. No large radiative corrections

Large/small angles kinematic in ISR



~10% ISR events,
M_h<3 GeV

~90% ISR events,
because of ISR boost
M_h> 3 GeV

$e^+e^- \to p\bar{p}$ analysis, SA ISR kinematics

Main selection criteria, SA case

$1 - \text{two tracks}: p, \bar{p}$

$2 - M^2_{miss} < 1\,\text{GeV}/c^2$

$3 - P_{trans.} < 0.15\,\text{GeV}/c$

$4 - P_p < 5\,\text{GeV}/c$

Backgrounds

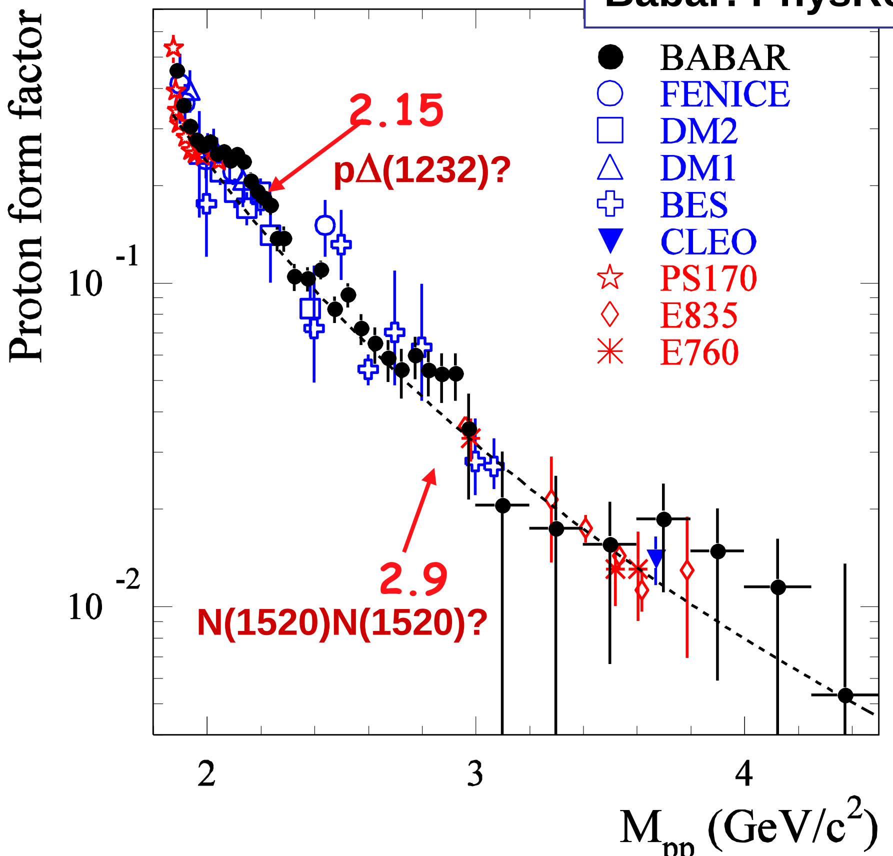
$1 - \text{Two photon} - e^+e^- \to e^+e^- p\bar{p}, \sim 3\%$

$2 - \text{ISR with } \pi^0 : e^+e^- \to \gamma p\bar{p}\pi^0, \sim 5\%$

Systematics: ~3%

$e^+e^- \rightarrow p\bar{p}$ LA ISR kinematics

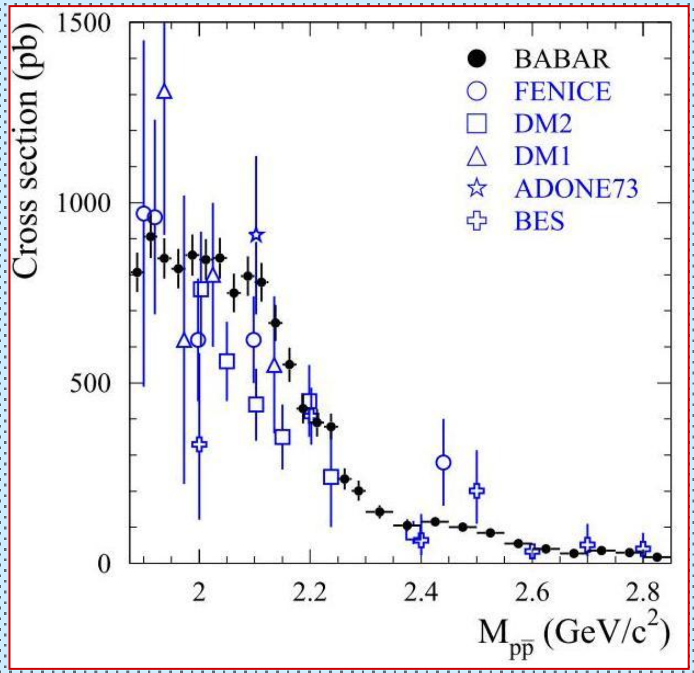
Babar: PhysRevD.87.092005(2013)



Fit:

$$F_{pp} \sim \frac{\alpha_s^2(m)}{m^4} \sim \frac{C}{m^4 \ln^2(m^2/\Lambda^2)}$$

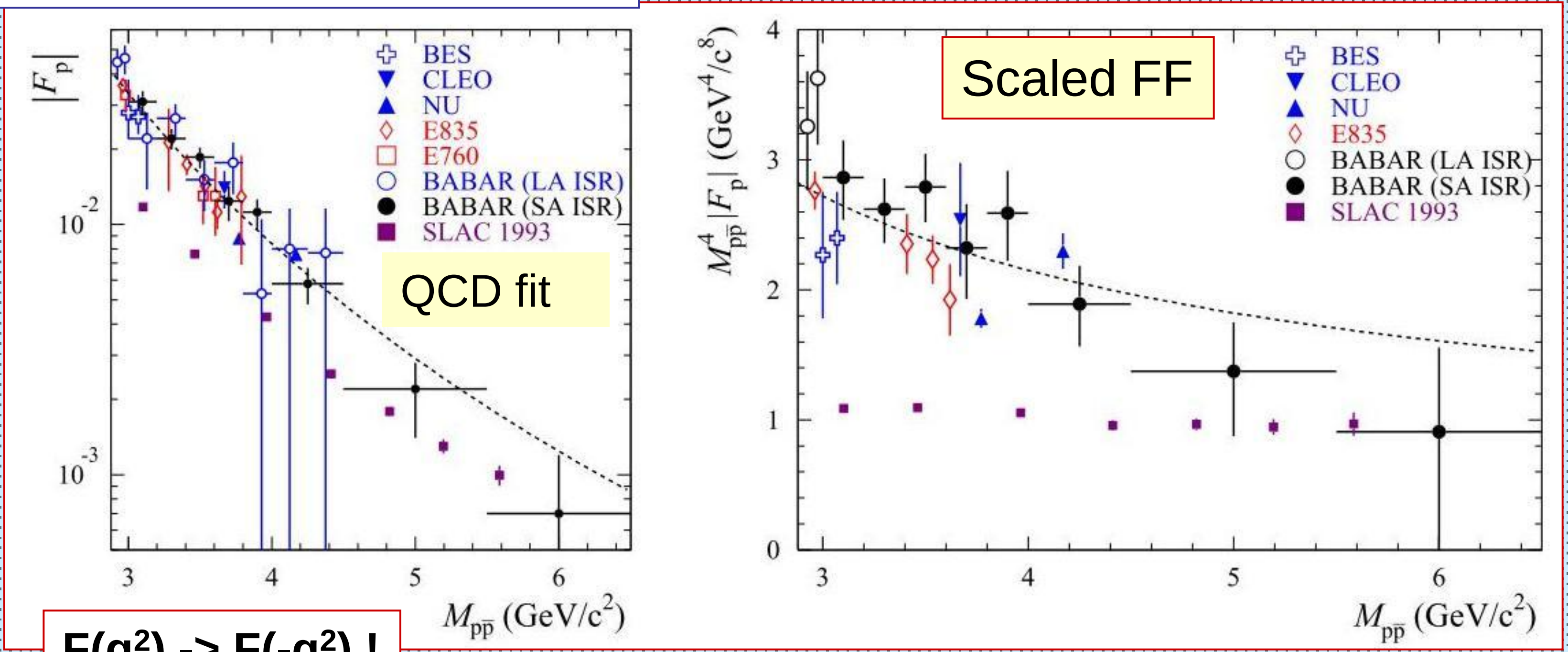
FF ~ 1 at threshold



Babar results are in agreement with previous data and more precise

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

Babar: PhysRevD.88.072009(2013)



F(q²) -> F(-q²) !

Babar results are in agreement with previous data at E<4 GeV,
And have a tendency to approach spacelike FF at E>4 GeV

The charged kaon form factor

Two BABAR works :

1 - Phys.Rev.D88 032013 (2013) - E < 5 GeV/c^2 - LA ISR

2 – Preliminary - E < 7.5 GeV/c^2 - SA ISR

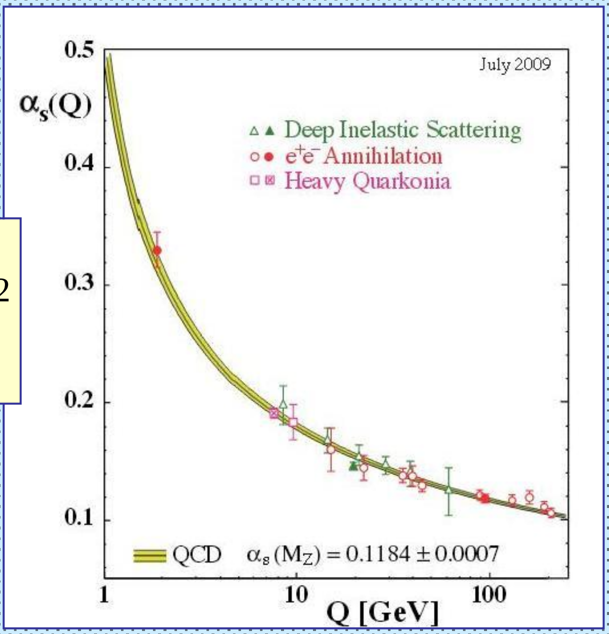
The charged kaon form factor

$e^+e^- \to K^+K^-$,
$J^{PC}=1^{--}$, L=J=1
P-wave

$$\sigma_{K^+K^-}(s) = \frac{\pi\alpha^2\beta^3}{3s}|F_K|^2,$$

$$F_K = \frac{8\pi\alpha_s f_K}{s}$$

$$\alpha_S \sim \frac{C}{\ln(m^2/\Lambda^2)}$$



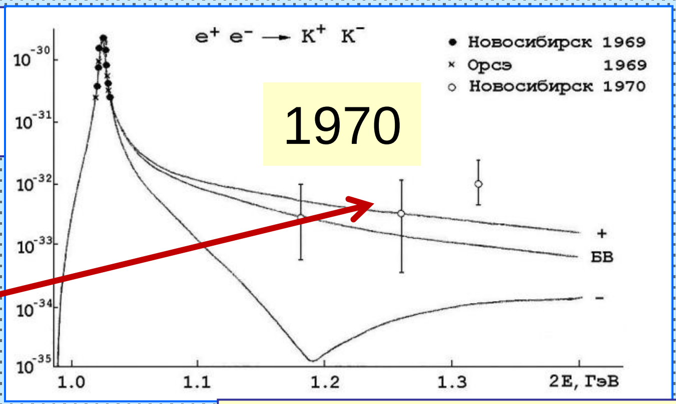
$$\Gamma(K \to l\nu) = \frac{G_F^{\ 2}}{8\pi} f_K^{\ 2} M_K^{\ 2}(1-(\frac{m_l}{m_K})^2)^2 |V_{qs}|^2$$

$$f_K = 156 MeV$$

The history of kaon TL form factor above ϕ(1020)

1. $e^+e^- \to K^+K^-$

VEPP-2 (1970), Adone, DCI, VEPP-2M



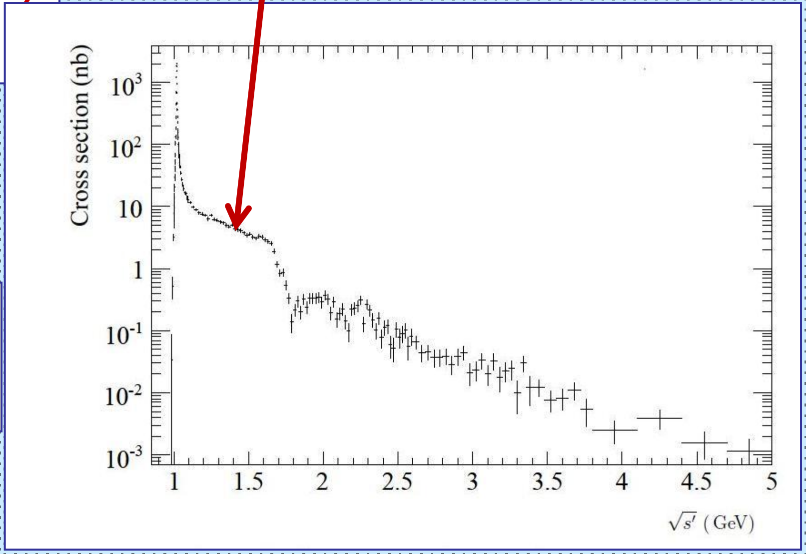
1970

Phys.Lett. 41B 205 (1972)

$\sigma \sim 5$ nb

2. $e^+e^- \to K^+K^- \gamma$ (ISR)

Babar (2013)



in 40 years
10^6 times in Lum.!

e^+e^- -> K^+K^- analysis, SA ISR

Main selection criteria

$1 - \text{two tracks}: K^+, K^-$

$2 - M^2_{miss} < 1\,GeV/c^2$

$3 - P_{trans.} < 0.15\,GeV/c$

$4 - P_K < 5\,GeV/c$

Background

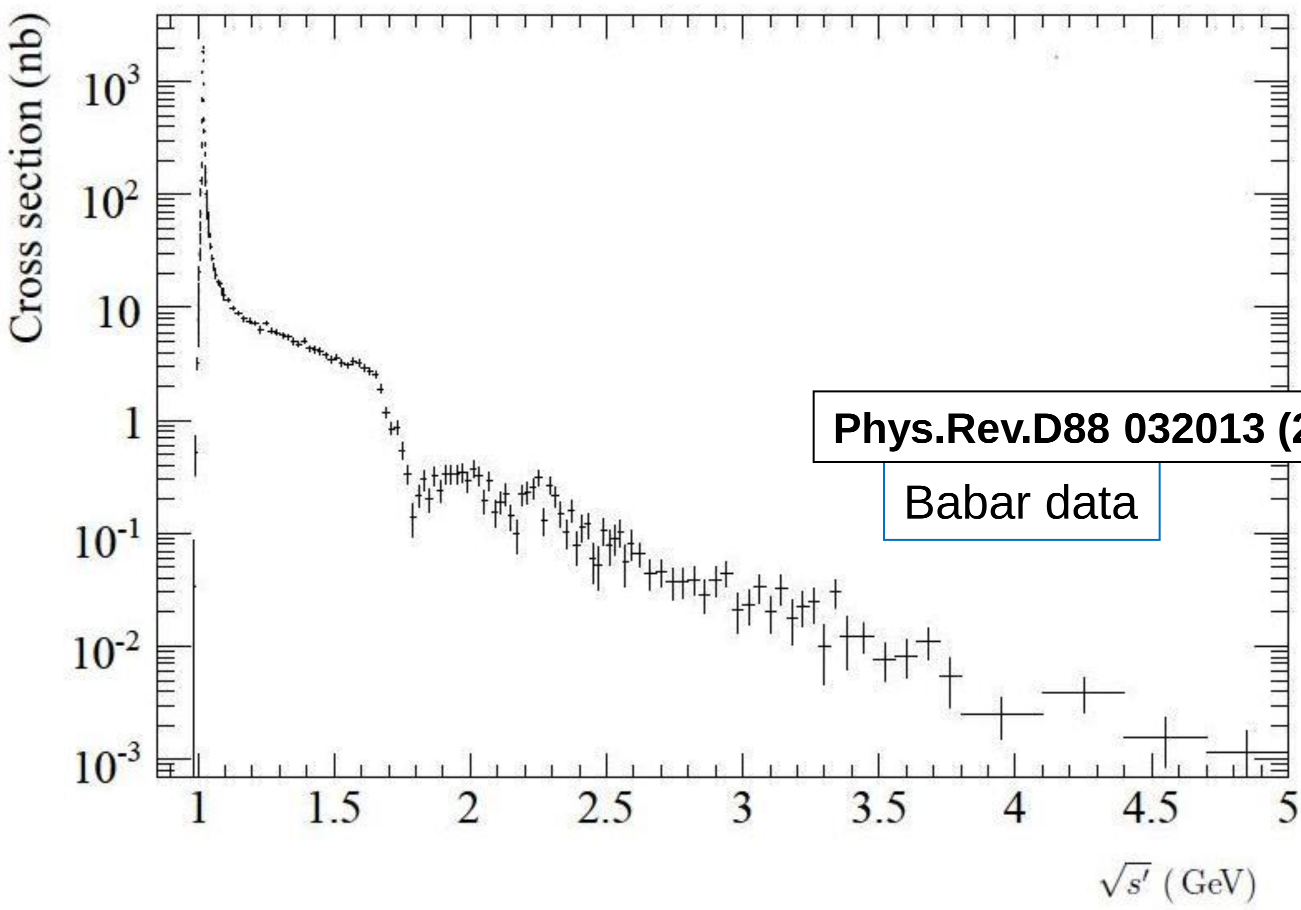
$1 - \text{Two photon} - e^+e^- \to e^+e^-\ K^+K^-, \sim 3\%$

$2 - \text{ISR with } \pi^0 : e^+e^- \to \gamma K^+K^-\ \pi^0, \sim 5\%$

$3 - \text{ISRmisID} : e^+e^- \to \gamma\mu^+\mu^-, \sim 5\%$

Systematics ~ 3%

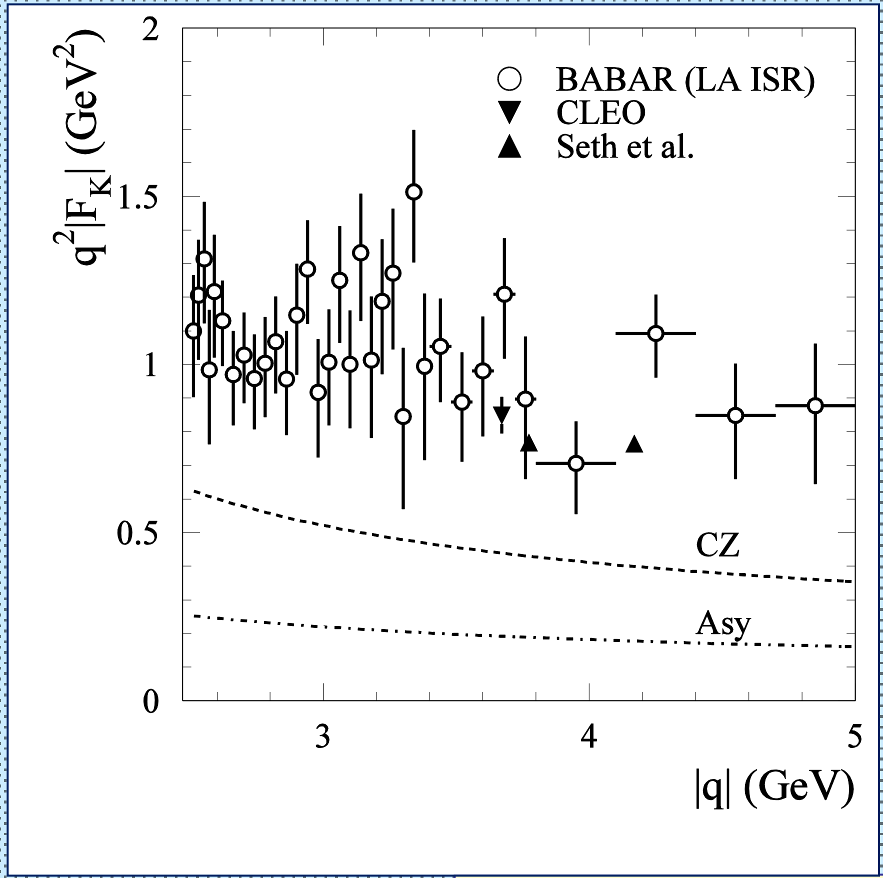
$e^+e^- \to K^+K^-$ cross section



Phys.Rev.D88 032013 (2013)

Babar data

Kaon form factor , LA ISR



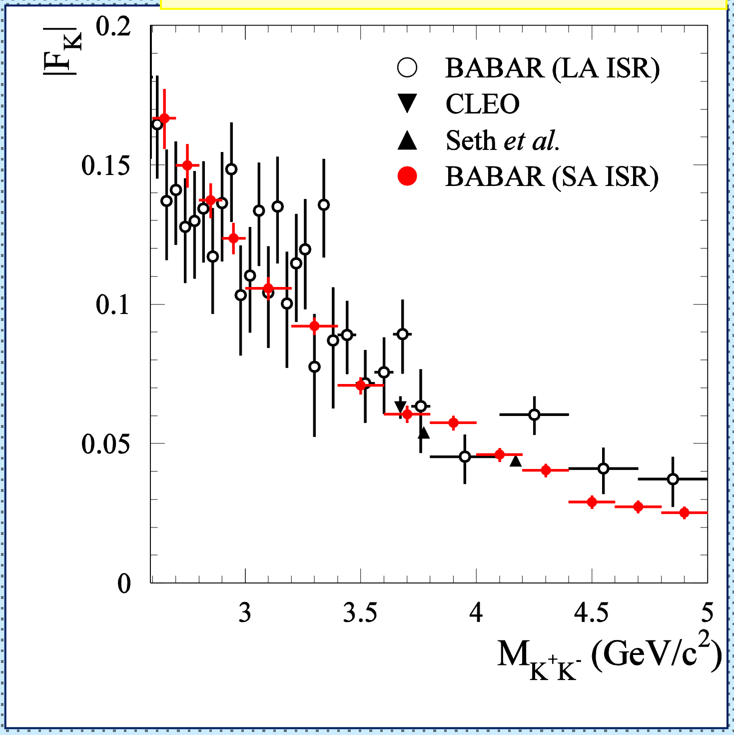
Data are higher the QCD prediction by 4 times

Phys.Rev.D88 032013 (2013)

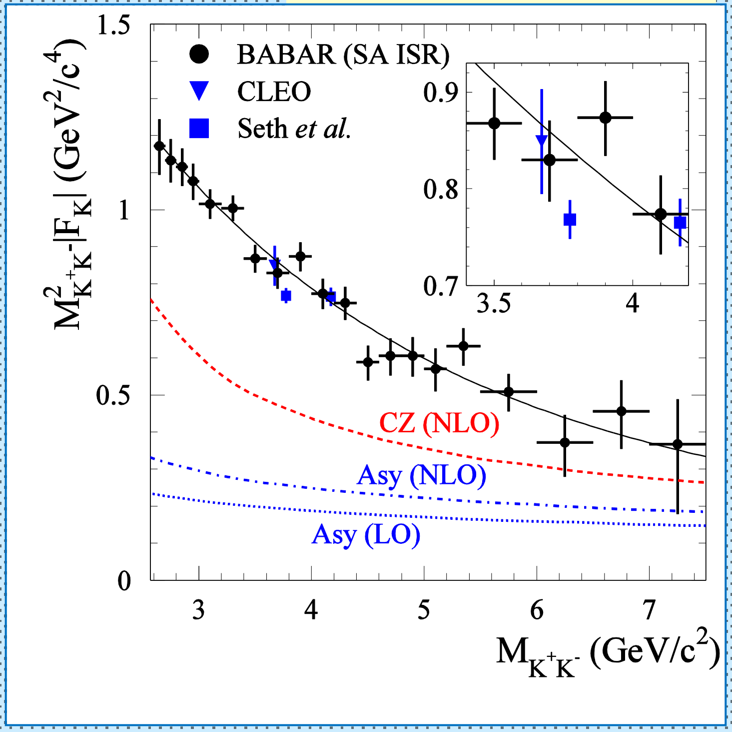
CZ: Z.Ph. C42 569 (1989)

Kaon form factor, SA ISR, Babar preliminary

SA – LA ISR comparison



Scaled form factor



The kaon form factor with SA ISR technique agrees with LA ISR data and more precise. At E > 5 GeV/c² the tendency to approach to the QCD limit is seen.

Conclusions on the proton timelike form factor (FF)

1. Using the ISR method in Babar the proton FF has been measured from the threshold up to 6 GeV
2. Near the threshold the proton FF is close to the pointlike value 1.
3. The $e^+e^- > p\bar{p}$ cross section is nearly constant from the threshold up to 2.2 GeV.
4. A resonance structure in proton FF is seen in the region 2-3 GeV
5. Beginning from q=5 GeV the proton FF reveals the tendency to approach to the QCD prediction $F(q^2)=F(-q^2)$.

Conclusions on the charged kaon timelike form factor (FF)

1. Using the ISR method in Babar the charged kaon FF has been measured from the threshold up to 7 GeV
2. Below 2 GeV in the kaon FF the resonance structure is seen.
3. At E<4 GeV the kaon FF is ~ 4 times higher than the QCD limit
4. At E>5 GeV the kaon FF approaches to the QCD limit

Thank you for attention