Interference effects in vacuum hadron polarization...

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Outline

- Introduction
- Theory of $e^+e^- \to \mu^+\mu^-$ for KLOE
- Results and extraction of Π_h
- Running QED coupling at energy of ρ (KLOE 2016)

Introduction

based on : "Hadronic vacuum polarization in $e^+e^- \to \mu^+\mu^-$ process bellow 3 GeV, arXiV 1704.01887"

Test of SM is based on comparison between theory and experiment.

a_μ, α_{M_Z},....

Π_h plays crucial role

$\Pi^{\mu\nu}(x) = \Sigma_q Tr < j_q^\mu(x) j_q^\nu(0) >$

$\Pi^{\mu\nu}(q) = P_T^{\mu\nu}\Pi_h(q^2) = Tr \int_k \Gamma^\mu(k,p) S_q(k)\gamma^\mu S_q(p)$

Theory of $e^+e^- \to \mu^+\mu^-$ for KLOE

Interference effects between hadronic and leptonic vacuum polarization are observed in close vicinity of narrow resonances: J/Ψ,Ψ, Υ as well as ϕ and ω.

They have unique interference pattern and appears in all predominantly QED process in the timelike momentum channel. 1963 estimate : In vicinity of resonances the charges changes like :

$$e^2 \to e^2 \left(1 - \frac{3 m_V \Gamma_{ll} \alpha^{-1}}{m_V^2 - s + im\Gamma}\right) , \tag{1}$$

Recently ϕ meson sector measured by KLOE in 2004 and SND 2001.

Experiment. data: F. A. Ambrosino, et. al. Phys. Lett. B 608 (2005). see also M.N. Achasov NPA 675, 2000, PRL 86 (2001)

Using $+\gamma$ process the running coupling has been measured by KLOE 2015.

To see the effect, the high precision measurement is required

$\epsilon(= \sigma_{stat})(m_\phi)) = 0.1nb$ with KLOE experimental setup, $\sigma(m_\phi) \equiv 40nb$.

Using SM, the cross section reads (in next to (next) leading order)

$$\sigma(s) = \frac{4\pi C_t}{|1 - \Pi(s)|^2} \left[\sigma_A(s) \left(2 - \beta_\mu^2 (1 - \frac{C_t^2}{3}) \right) + \sigma_B(s) \right] , \tag{2}$$

where $C_t = \cos(\theta_{min})$ with $\theta_{min} = 50^0$ ($\theta_{max} = 140^o$), which is KLOE experimental cut on polar scattering angle between μ^- and e^- particles and $\beta_\mu = \sqrt{1 - 4m_\mu^2/s}$.

$$\sigma_B(s) = -\frac{\alpha^3}{4\pi s}(1 - \beta_\mu^2) \ln \frac{1 + \beta_\mu}{1 - \beta_\mu} . \tag{3}$$

$\sigma_A(s)$- the dominant term, listed completely in Arbuzov1997 (9702262), collects all leading logs of Dirac and Pauli form factors and the known soft photon contributions for which we take $ln\frac{\Delta\epsilon}{\epsilon} = 0.05$ (15 MeV cut on c.m.s. soft photon energy at ϕ peak).

Theory of $e^+e^- \to \mu^+\mu^-$ for KLOE

Nontrivial information is in $\Pi(s) = \Pi_l(s) + \Pi_h(s)$

which completes $\alpha(s) = \frac{\alpha}{1-\Pi(s)}$

$\alpha = \alpha(0) = 1/137.0359991390$

$\Pi_l(s)$- includes complete one loop + leading log in $(\alpha)^2$

hadronic vacuum polarization Π_h-driven by strong coupling QCD

$$\Pi_h(s) = \frac{s}{4\pi^2\alpha} \int_{4m_\pi^2}^{\infty} d\omega \frac{\sigma_h(\omega) \left[\frac{\alpha}{\alpha(\omega)}\right]^2}{\omega - s + i\epsilon} \, . \tag{4}$$

$\sigma_h = \sigma(e^+e^- \to hadrons)$

Theory of $e^+e^- \to \mu^+\mu^-$ for KLOE

For σ_h dominant bellow 3GeV we use

this millennium published data for exclusive channels:

e^+e^-–> $\pi\pi$, K^+K^-, K_LK_S, $\pi\pi\pi$ and $\eta\gamma$

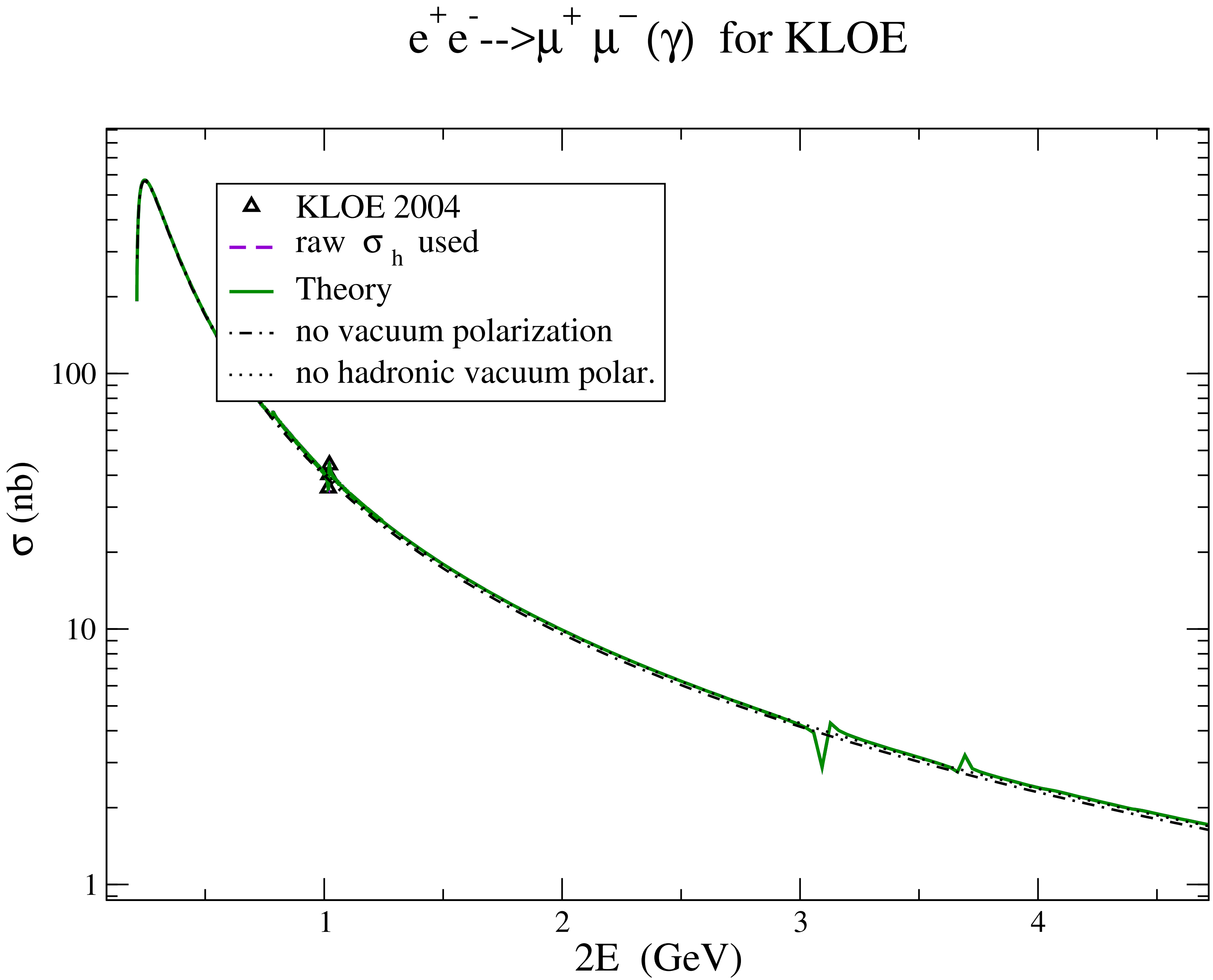
from **SND, CMD, CMD2, KLOE, BABAR , BESSIII** collab.

For each channel we find fit valid for all s and generate quasidata, from which we calculate Π_h.

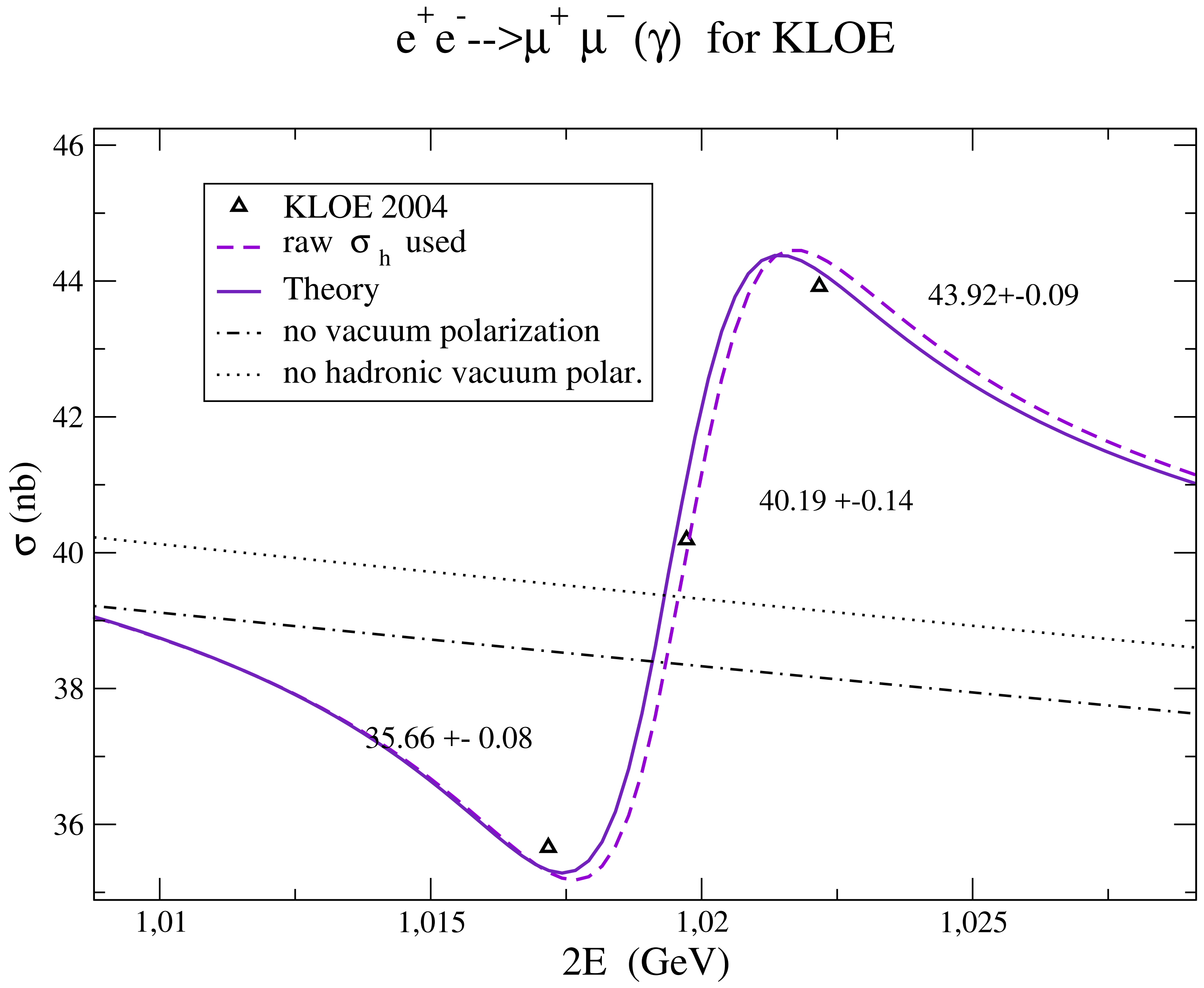
Existing fits for σ_i and ϵ_i are explored and refitted.

$\sigma_h^0 = \sigma_h(s)(|1 - \Pi(s)|)^2$ calculated

Above 3 GeV all important narrow quarkonia are included also 1 loops PT QCD for b,c are added for all s (almost no effect)

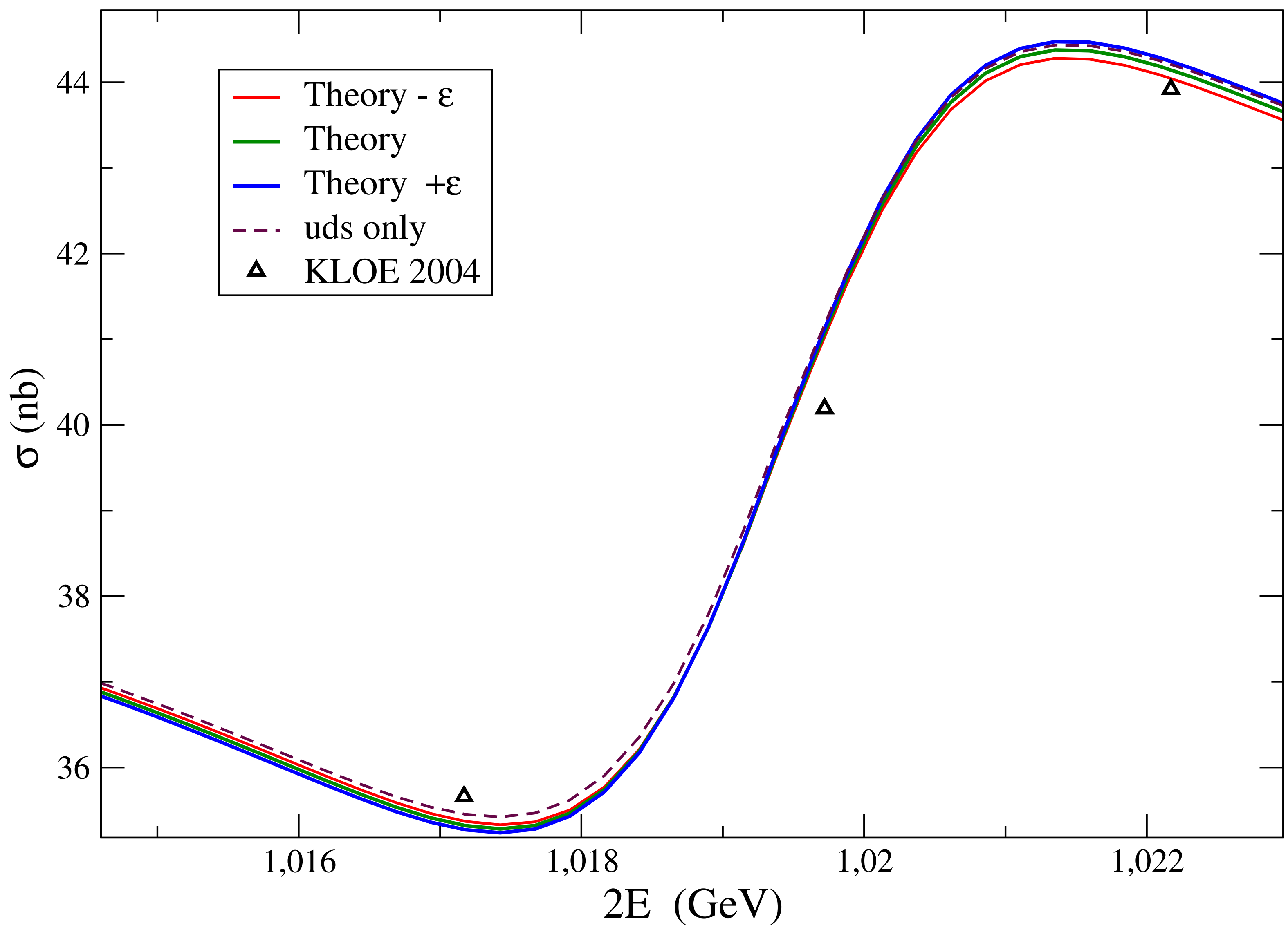


e+e- --> μ+ μ− (γ) for KLOE
KLOE 2004
raw σ h used
Theory
no vacuum polarization
no hadronic vacuum polar.
σ (nb)
2E (GeV)
100
10
1
1
2
3
4



e+e- --> μ+ μ− (γ) for KLOE
KLOE 2004
raw σ h used
Theory
no vacuum polarization
no hadronic vacuum polar.
43.92+-0.09
40.19 +-0.14
35.66 +- 0.08
σ (nb)
46
44
42
40
38
36
1,01
1,015
1,02
1,025
2E (GeV)

$e^+e^- \to \mu^+\mu^-(\gamma)$ for KLOE



Fits of σ_h

Sum of (un)dressed BW with complex phases

Gounaris-Sakurai VMD, Kuhn-Santamaria model

BABAR 2012 fit $\pi\pi$

modified BABAR fits 2013 for K^+K^-

modified SND fit for K^LK^S

own fits for 3π and $\eta\gamma$

fits of errors $\epsilon(s)$ of $\sigma_h(s)$ overestimating fit formula

$$\epsilon[nb] = c\sqrt{\sigma_h[nb]}\ ; c = 0.8nb^{1/2} \tag{5}$$

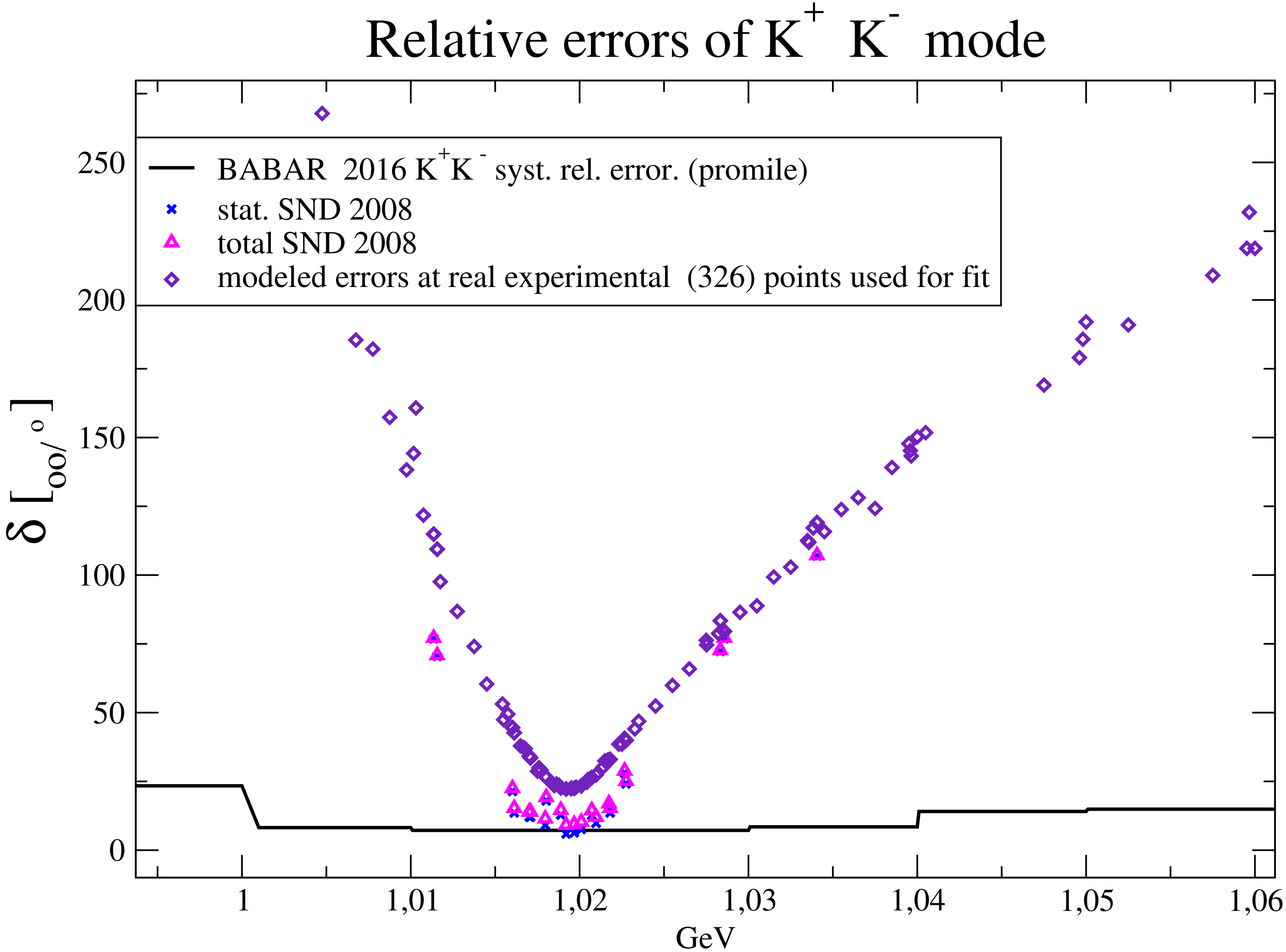
such that $\epsilon > \sigma_{TOT} = \sqrt{\sigma^2_{syst} + \sigma^2_{stat.}}$ where σ_{TOT} are the best data in given kinematical region.

Requirements for minimized χ^2

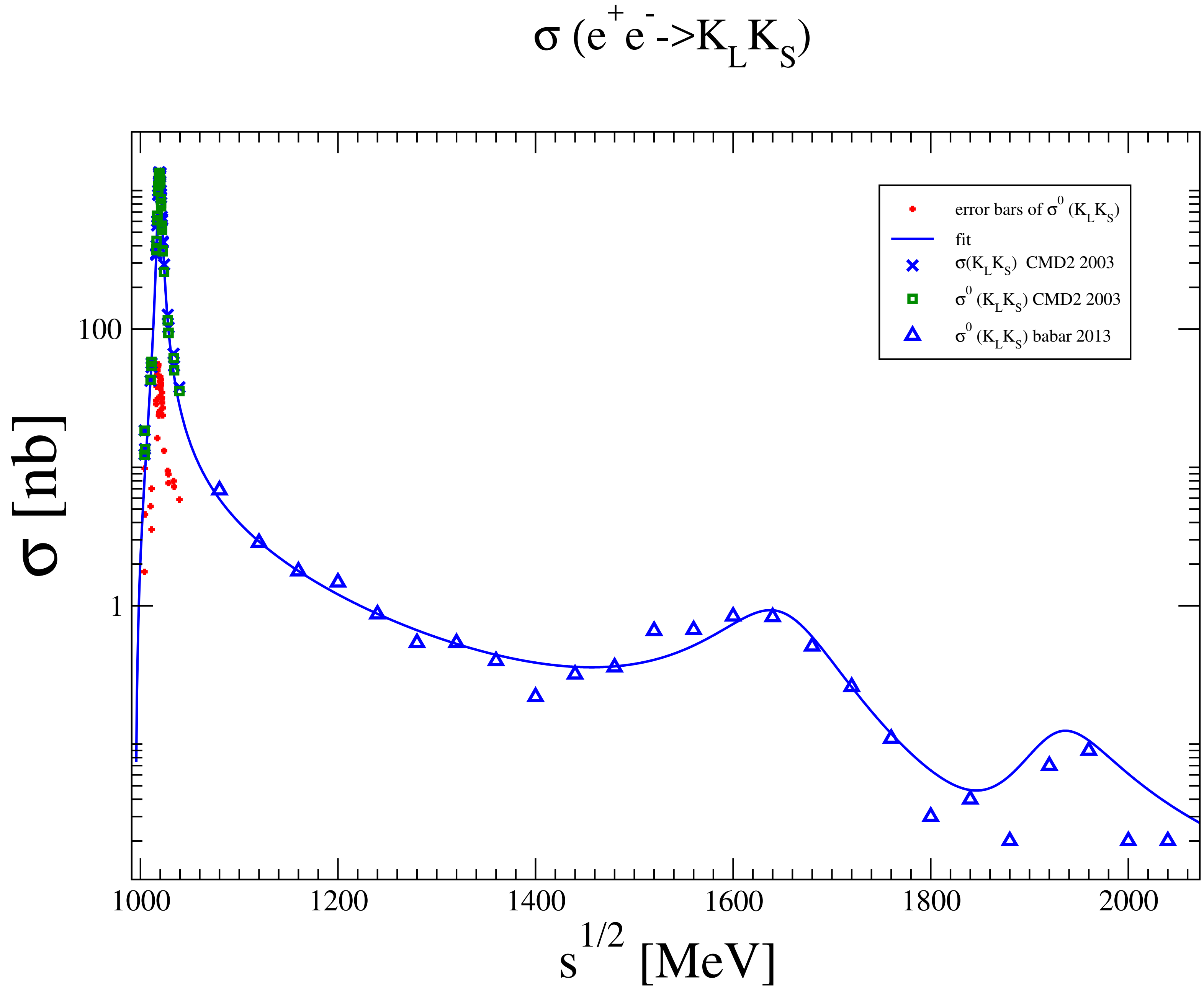
$\chi^2 \simeq 1$ for single data, $\chi^2(\sigma_{stat} \to \epsilon) \simeq 1$ for combined data , note usually $\chi^2(\sigma_{stat} \to \epsilon) << 1$ for single data

Example $\chi^2(\sigma_{stat} \to \epsilon) = 0.123$ for BABAR 2013 K^+K^- and $\chi^2(\sigma_{stat} \to \epsilon) = 0.3$ for combined data

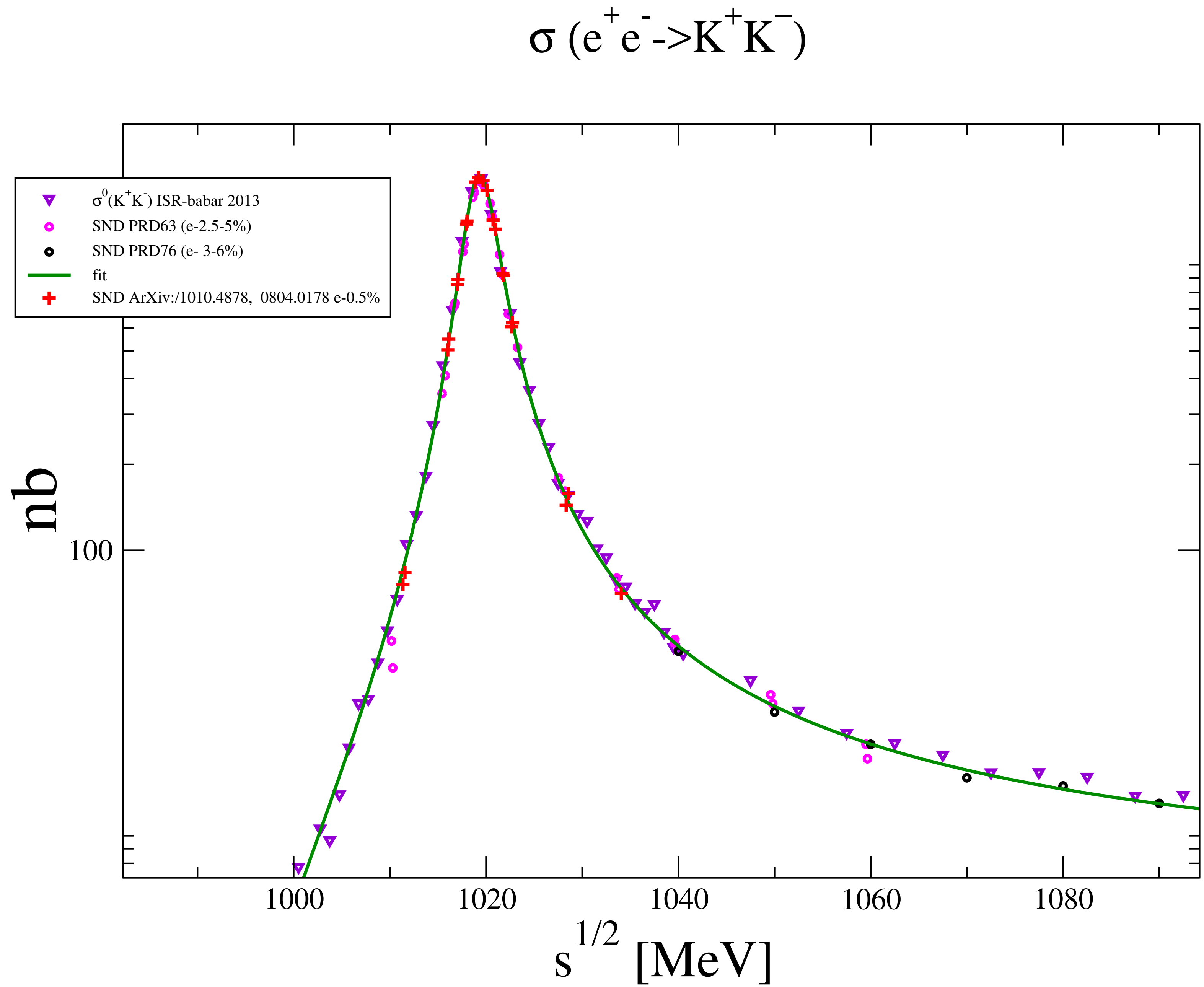
Fits of $\sigma_{K^+K^-}$,....



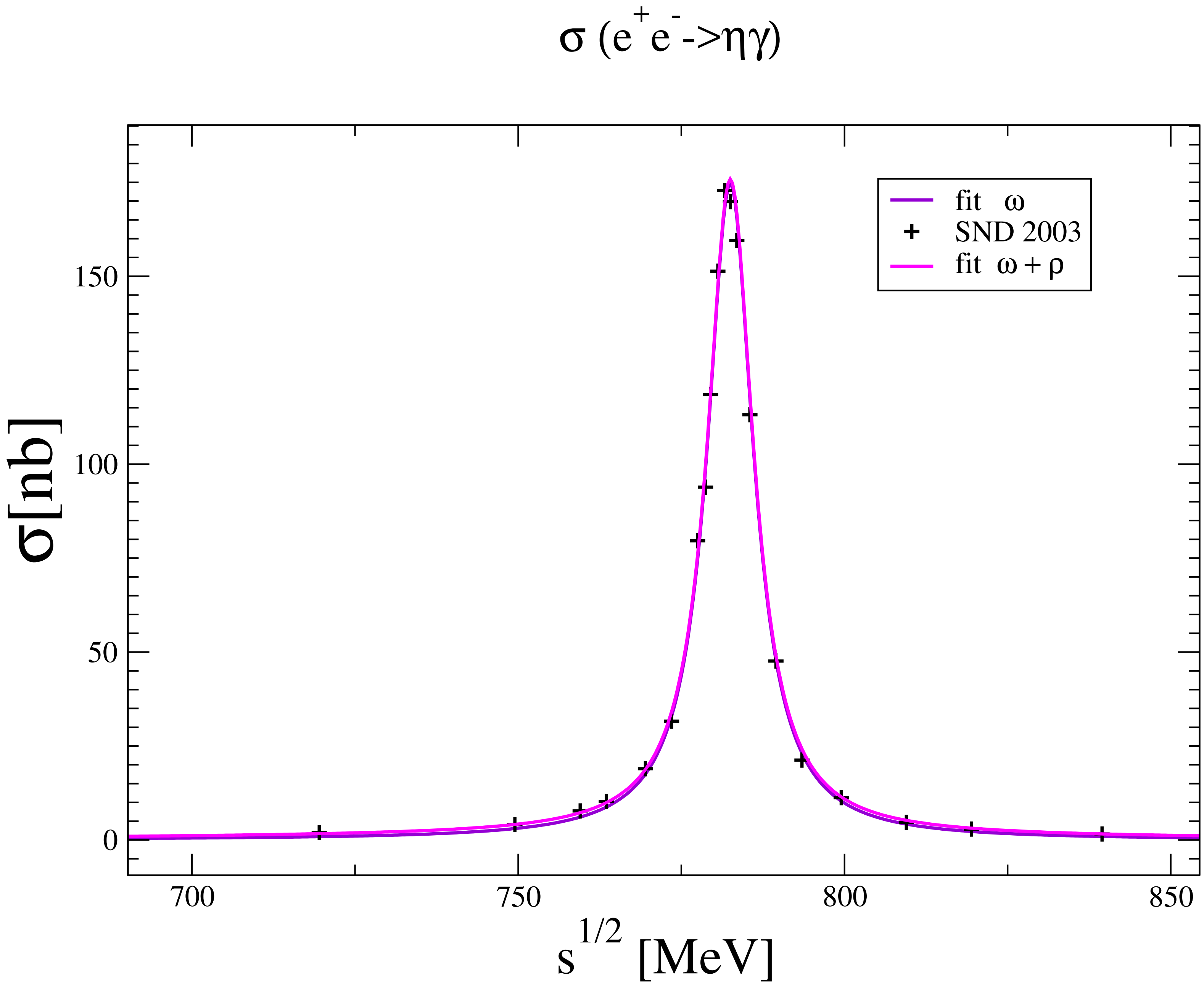
Relative errors of K+ K- mode
BABAR 2016 K+K - syst. rel. error. (promile)
stat. SND 2008
total SND 2008
modeled errors at real experimental (326) points used for fit
δ [oo/o]
0
50
100
150
200
250
1
1,01
1,02
1,03
1,04
1,05
1,06
GeV

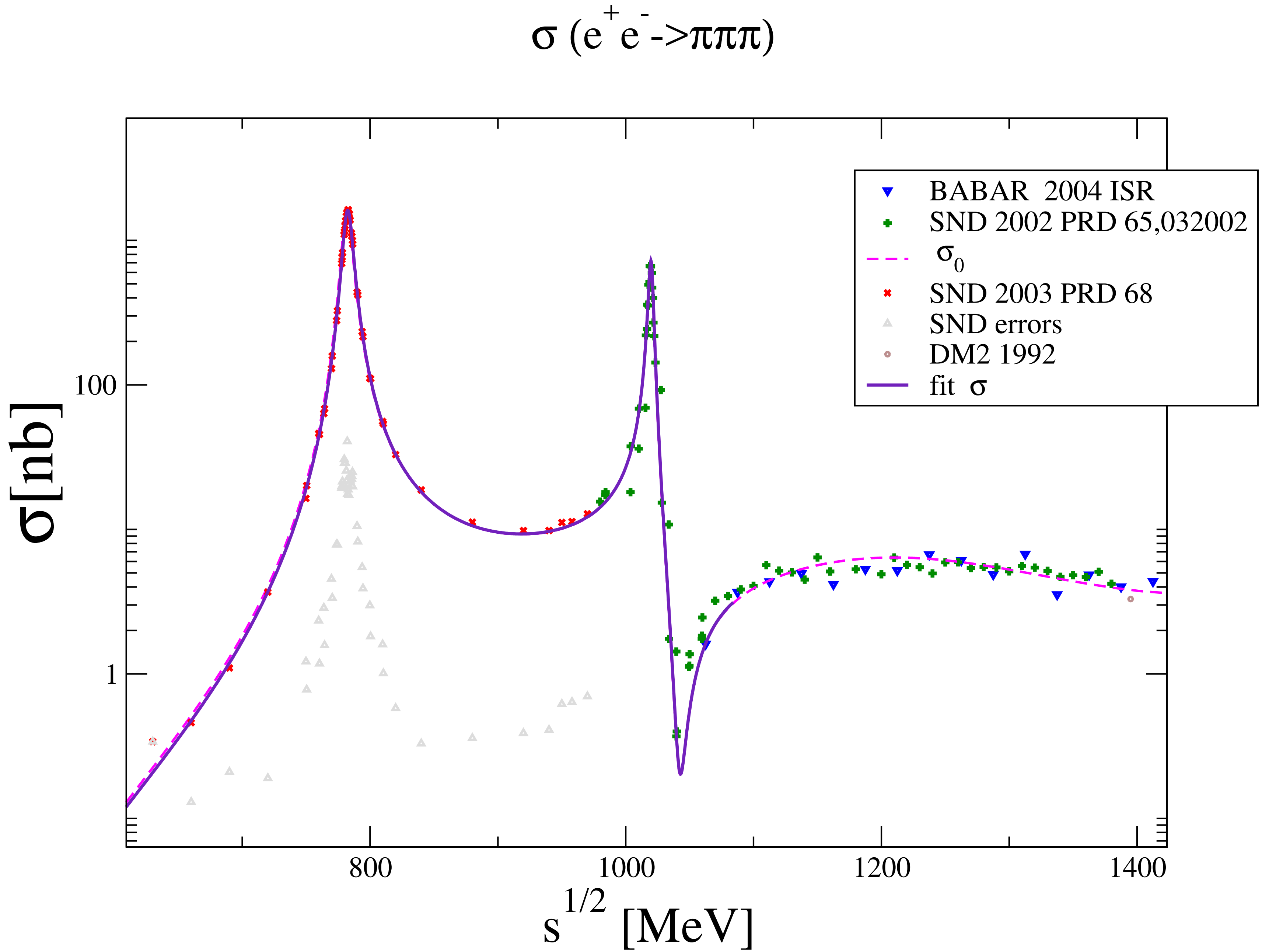


σ (e+e- ->KLKS)
error bars of σ0 (KLKS)
fit
σ(KLKS) CMD2 2003
σ0 (KLKS) CMD2 2003
σ0 (KLKS) babar 2013
100
1
σ [nb]
1000
1200
1400
1600
1800
2000
s1/2 [MeV]



σ (e+e- ->K+K−)
σ0(K+K-) ISR-babar 2013
SND PRD63 (e-2.5-5%)
SND PRD76 (e- 3-6%)
fit
SND ArXiv:/1010.4878, 0804.0178 e-0.5%
nb
100
1000
1020
1040
1060
1080
s1/2 [MeV]


σ (e+e- ->ηγ)
σ[nb]
s^1/2 [MeV]
fit ω
SND 2003
fit ω + ρ
0
50
100
150
700
750
800
850

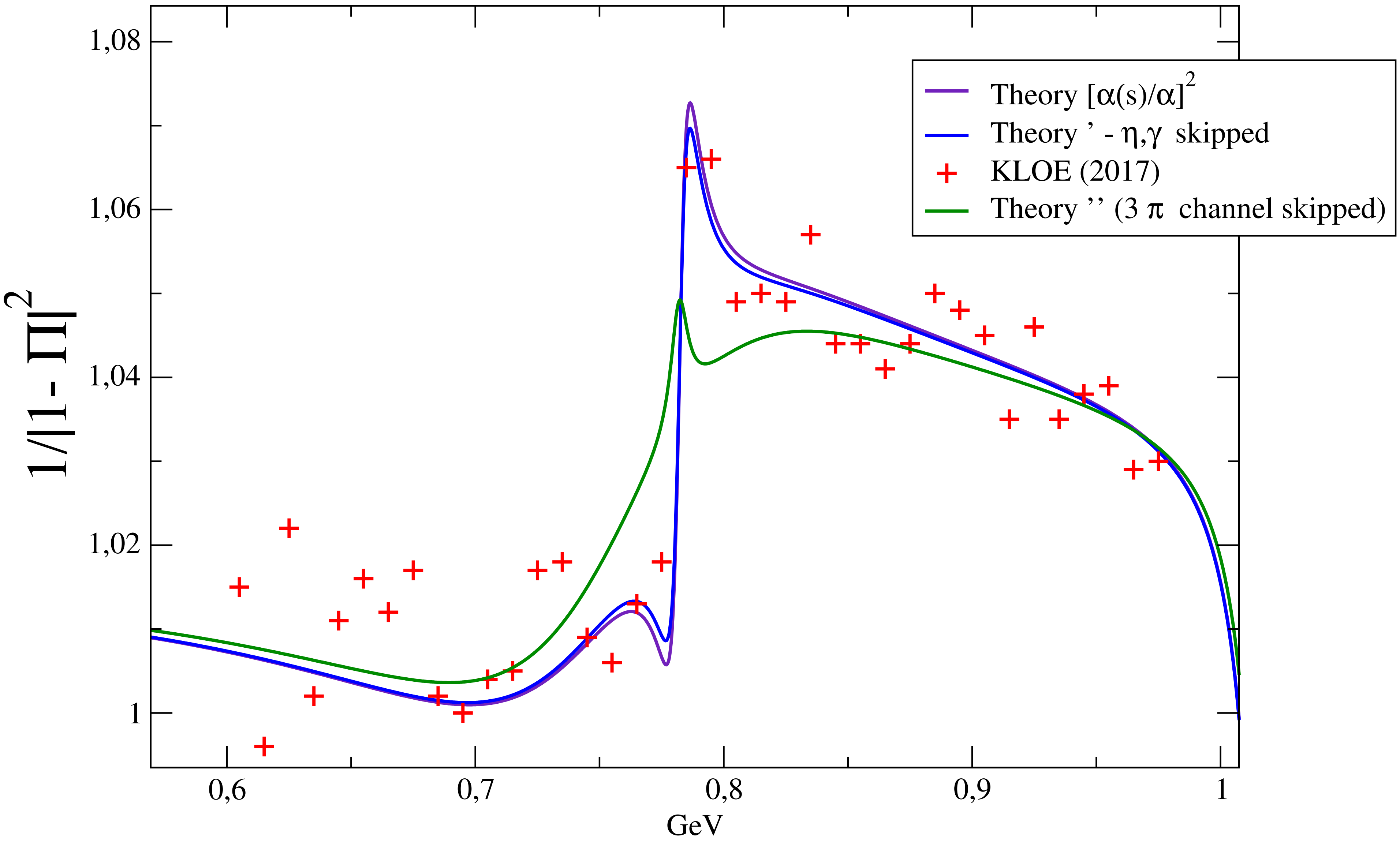

σ (e+e- ->πππ)
BABAR 2004 ISR
SND 2002 PRD 65,032002
σ0
SND 2003 PRD 68
SND errors
DM2 1992
fit σ
100
1
σ[nb]
800
1000
1200
1400
s1/2 [MeV]

Running α at ω

Never measured precisely in muon pair production

2016 KLOE collaboration studied process ee $\rightarrow \mu\mu\gamma(\gamma)$

KLOE 2016 α from ee -> μμγ(γ)



Conclusion

α_{QED} is complex at the timelike scale and runs in accordance with SM with

small, but statistically significant tension between Standard Theory and $e^+e^- \to \mu^+\mu^-$ 2004 KLOE experiment.

Explanation:

1. σ_h is systematically overestimated (few percentage, $s-$ dependent subtraction would be needed)

2. Analyticity is not an exact property of Π_h (there can be a contribution with different singular structure then a real axis poles and real branch points, their contribution should not be larger then 5%)

3. Speaker, you are listening now, made a bad mistake

4. Something else

5. Combination of 1,2,3,4