SFB 1044 THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

PRISMA

Dispersive analysis of hadronic light-by-light contribution to $(g\text{-}2)_\mu$

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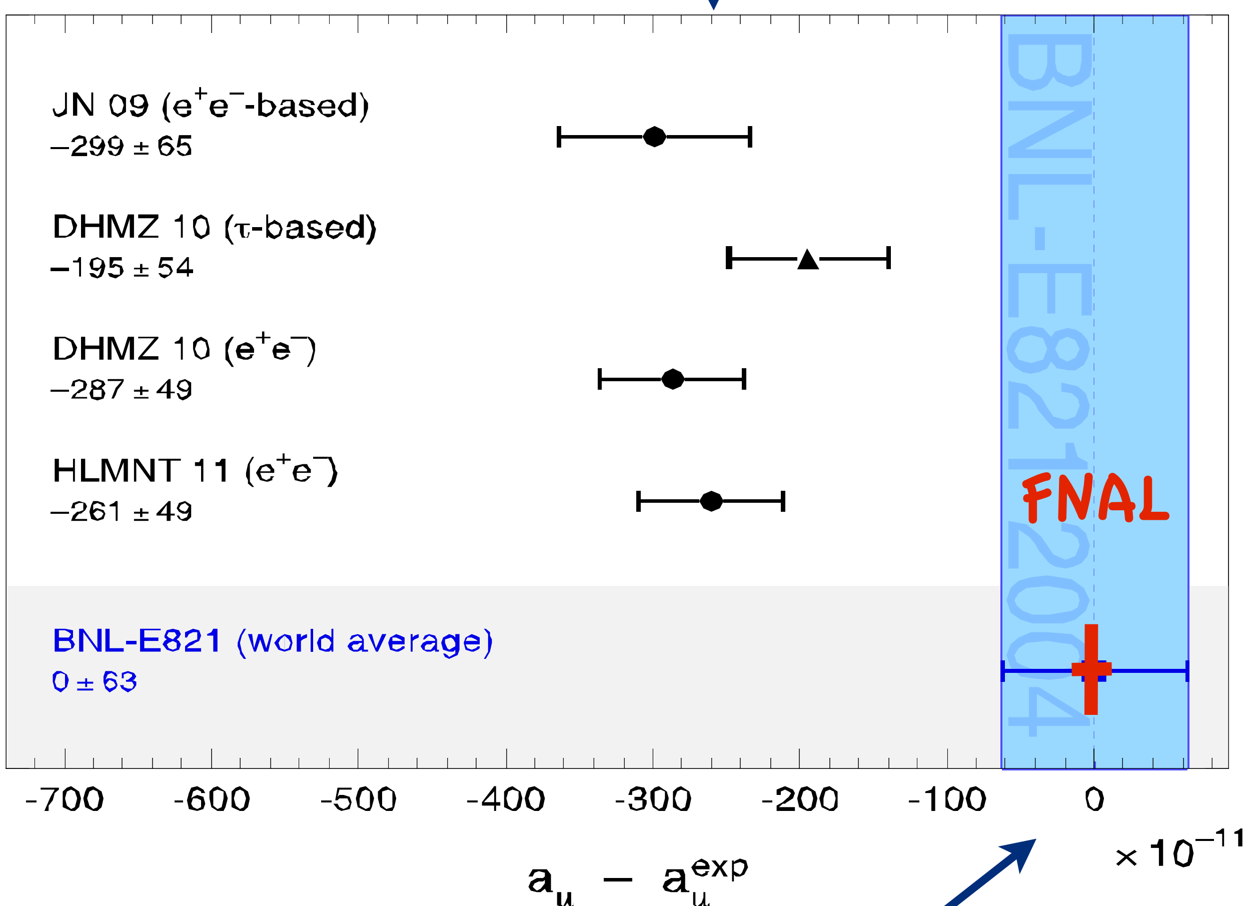
CIPANP 2018, May 29- June 3, 2018

Palm Springs, CA (USA)

$(g\text{-}2)_\mu$: theory vs experiment

SM predictions for a_μ



BNL-E821 measurement of a_μ

$a_\mu^{exp} = (11\ 659\ 208.9 \pm 6.3) \times 10^{-10}$

$a_\mu^{exp} - a_\mu^{SM} =$

$(28.1 \pm 3.6_{\ th} \pm 6.3_{\ exp}) \times 10^{-10}$

Teubner et al. (2017)

3 - 4 σ deviation from SM value !

Errors or new physics ?

New FNAL, J-PARC experiments

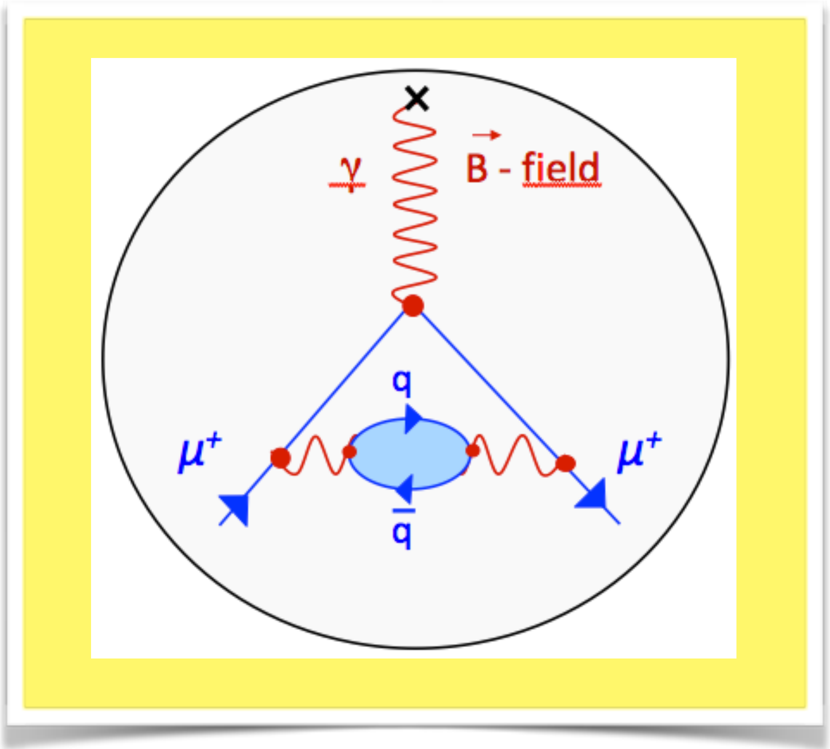
$\delta a_\mu^{FNAL} = 1.6 \times 10^{-10}$ talk R. Hong

factor 4 improvement in exp. error

-> Improve theory !

Hadronic contributions to $(g\text{-}2)_\mu$

hadronic vacuum polarization (HVP)

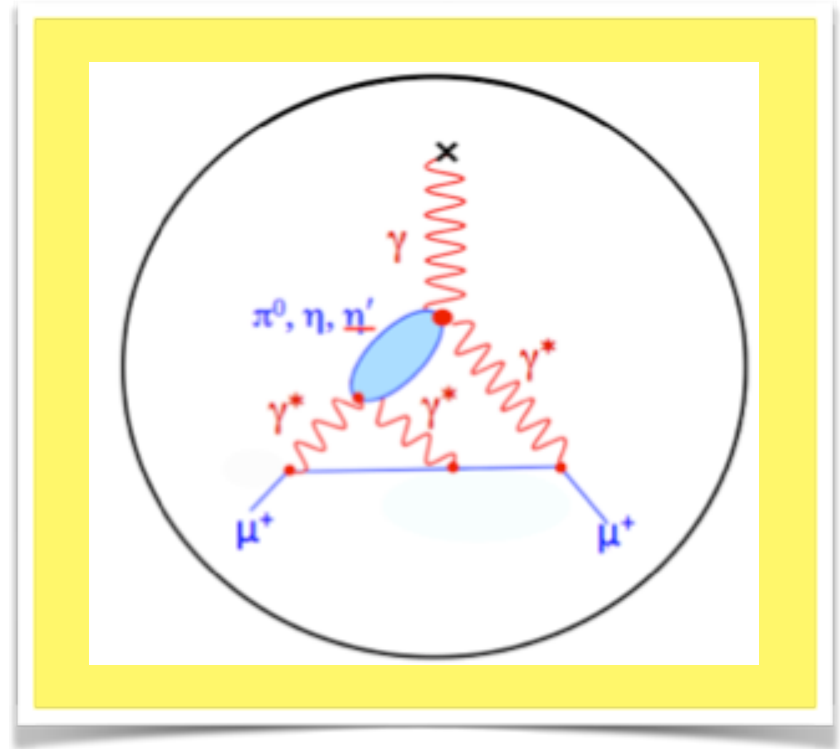


$a_\mu^{\text{l.o. had, VP}} = (692.2 \pm 2.5) \times 10^{-10}$

Teubner et al. (2017)

talk Ch. Redmer

hadronic light-by-light scattering (HLbL)



$a_\mu^{\text{had, LbL}} = (10.5 \pm 2.6) \times 10^{-10}$ (I)

$= (10.2 \pm 3.9) \times 10^{-10}$ (II)

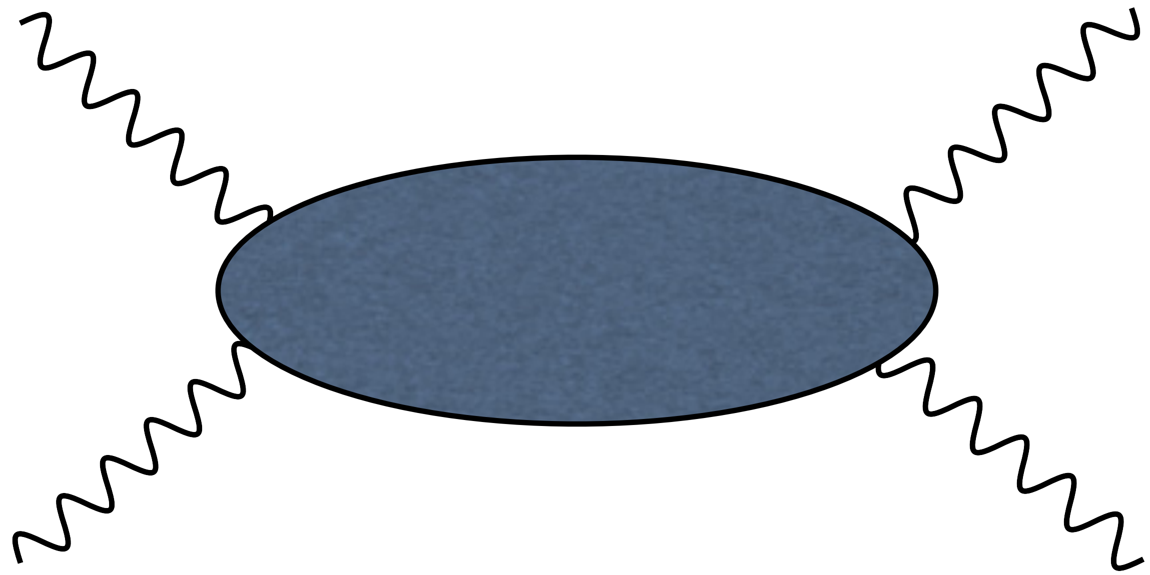
(I) Prades, de Rafael, Vainshtein (2009)

(II) Jegerlehner, Nyffeler (2009) Jegerlehner (2015)

New FNAL and J-Parc $(g\text{-}2)_\mu$ expt. : $\delta a_\mu^{exp} = 1.6 \times 10^{-10}$

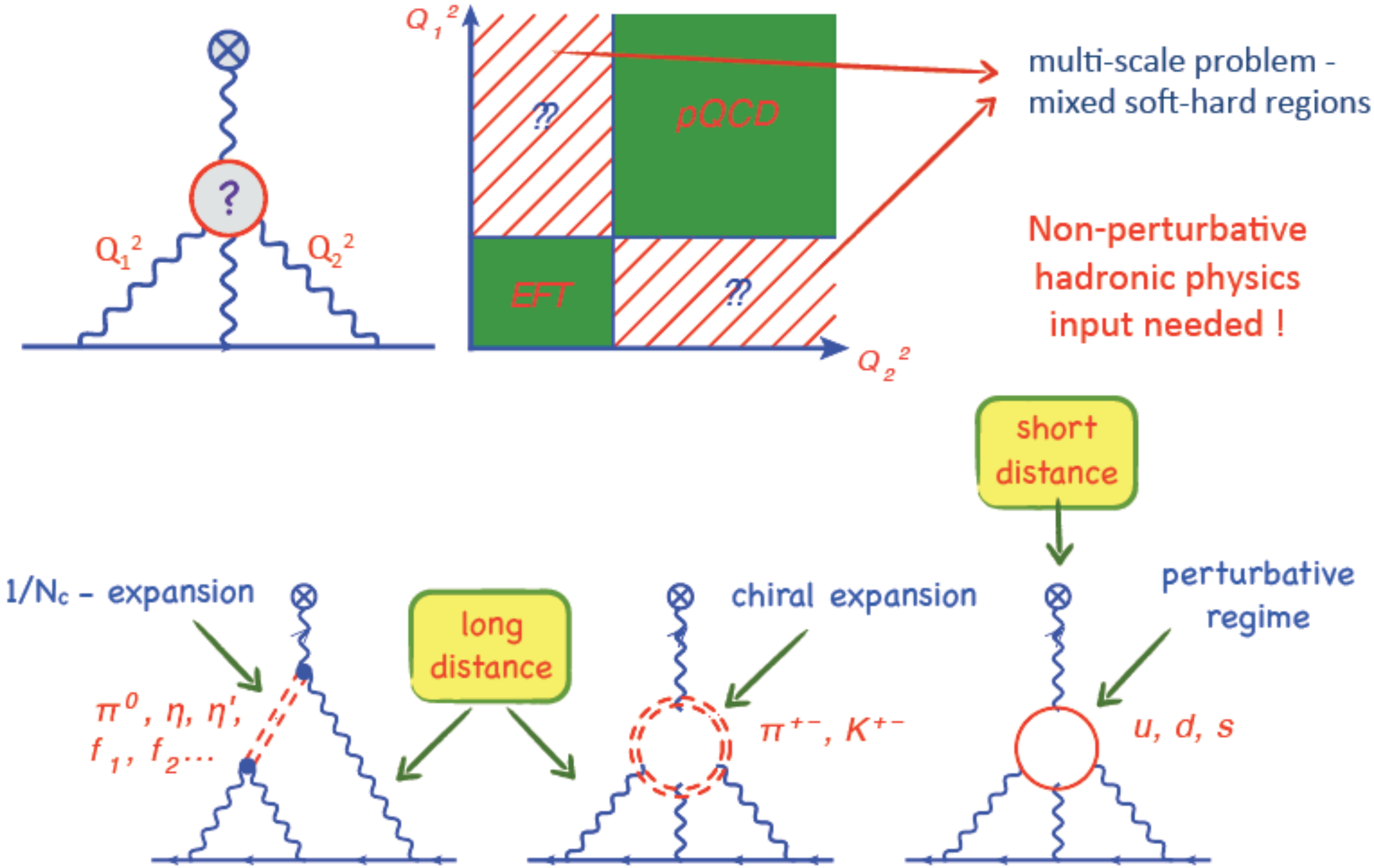
HVP determined by cross section measurements of e^+e^- -> hadrons

measurements of meson transition form factors required as input to reduce uncertainty



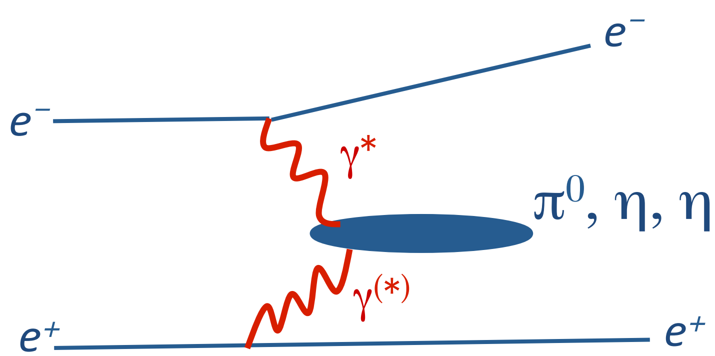
what is known about hadronic LbL scattering ?

hadronic LbL corrections to $(g\text{-}2)_\mu$: relevant contributions

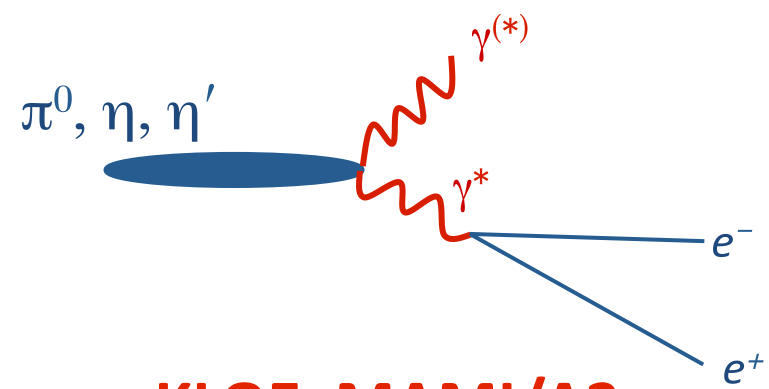


hadronic LbL corrections to $(g\text{-}2)_\mu$

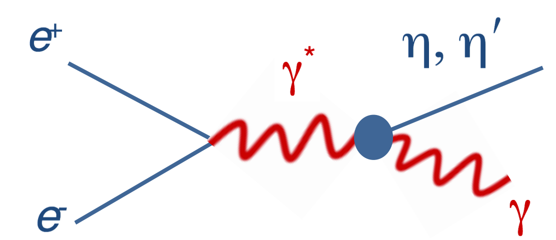
➡ **experimental input:** meson transition FFs, $\gamma^* \gamma^*$ -> multi-meson states, meson Dalitz decays



CLEO, BaBar, Belle, BESIII, ...



KLOE, MAMI/A2, BESIII, ...

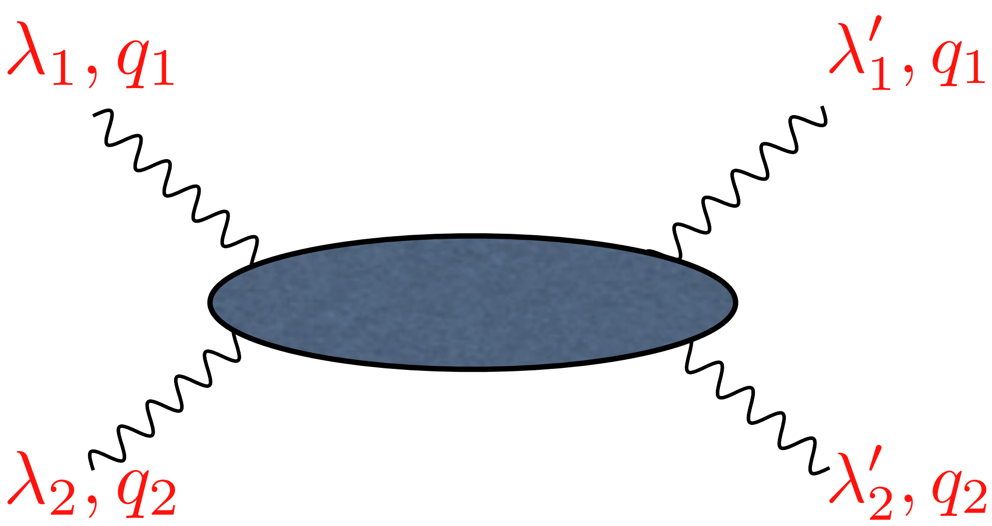


SND, CMD-2, BESIII, ...

➡ **theory deveolpments: -** sum rules, dispersion relations

- lattice QCD
- Dyson-Schwinger
- phenomenology, modeling

Theory: sum rules for LbL scattering (I)



$$\gamma^*(\lambda_1, q_1) + \gamma^*(\lambda_2, q_2) \to \gamma^*(\lambda'_1, q_1) + \gamma^*(\lambda'_2, q_2)$$

kinematical invariants:

$$s = (q_1 + q_2)^2, \qquad u = (q_1 - q_2)^2$$

$$\nu \equiv \frac{s-u}{4}, \quad Q_1^2 \equiv -q_1^2, \quad Q_2^2 \equiv -q_2^2$$

helicity amplitudes: $M_{\lambda'_1 \lambda'_2, \lambda_1 \lambda_2}(\nu, Q_1^2, Q_2^2)$ $\qquad \lambda = 0, \pm 1$

discrete symmetries: 81 → 8 independent amplitudes:

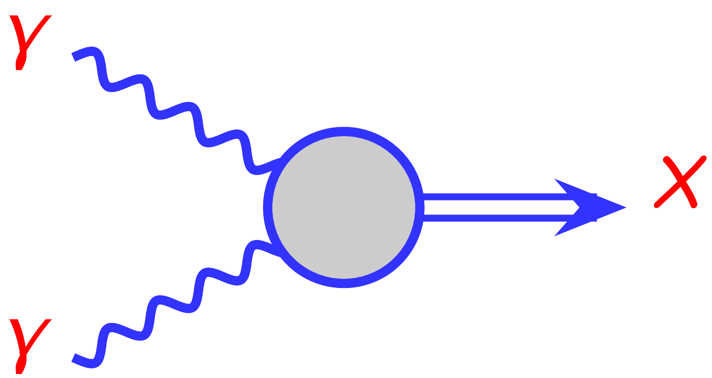
$$P: \quad M_{\lambda'_1 \lambda'_2, \lambda_1 \lambda_2} = M_{-\lambda'_1 -\lambda'_2, -\lambda_1 -\lambda_2}$$

$$T: \quad M_{\lambda'_1 \lambda'_2, \lambda_1 \lambda_2} = M_{\lambda_1 \lambda_2, \lambda'_1 \lambda'_2}$$

$M_{++,++},\ M_{+-,+-},\ M_{++,--},$ **T**

$M_{00,00},\ M_{+0,+0},\ M_{0+,0+},\ M_{++,00},\ M_{0+,-0}$ **T and L**

sum rules for LbL scattering (III)

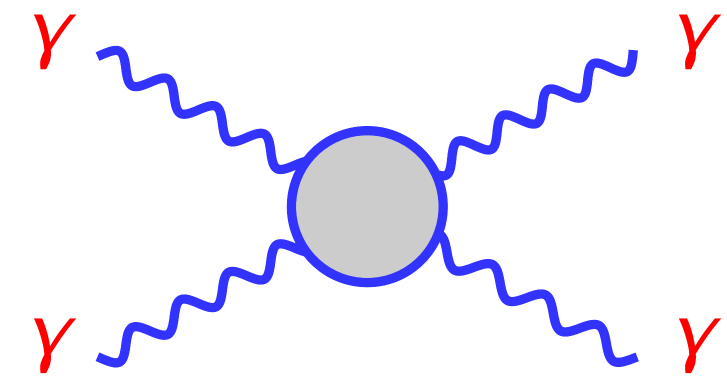


micro-causality

unitarity

LETs

dispersion theory



imaginary part of the amplitude - photon-photon fusion into leptons and hadrons:

$$\mathrm{Im} f^{(-)}(s) = -\frac{s}{8}[\sigma_2(s) - \sigma_0(s)]$$

$$\mathrm{Im} f^{(+)}(s) = -\frac{s}{8}[\sigma_{tot}(s)]$$

Sum rules

real part of the amplitude - low-energy structure of the elastic LbL scattering:

$$\mathcal{L}^{(8)} = c_1 (F_{\mu\nu}F^{\mu\nu})^2 + c_2 (F_{\mu\nu}\tilde{F}^{\mu\nu})^2$$

Euler, Heisenberg (1936)

$$\int_{s_0}^{\infty} \frac{ds}{s} [\sigma_2(s) - \sigma_0(s)] = 0$$

$$c_1 \pm c_2 = \frac{1}{8\pi} \int_{s_0}^{\infty} \frac{ds}{s^2} [\sigma_\parallel(s) \pm \sigma_\perp(s)]$$

sum rules for LbL scattering: 3 superconvergence relations

- helicity difference sum rule

for $Q^2 = 0$: GDH sum rule

Gerasimov, Moulin (1975), Brodsky, Schmidt (1995)

$$0 = \int_{s_0}^{\infty} ds \frac{1}{(s + Q_1^2)} [\sigma_0 - \sigma_2]_{Q_2^2=0}$$

the I=0 channel

meson contributions to helicity SR for $Q_1^2 = 0$ (in nb)

State	m (MeV)	$\Gamma_{\gamma\gamma}$(keV)		SR$_1$ ($Q^2 = 0$)
η	547.862±0.017	0.516±0.020		-193±7
η'	957±0.06	4.35±0.25		-304±17
$f_2(1270)$	1275.5±0.8	2.93±0.40	(Λ=2)	434±60
			(Λ=0)	≈0
$f_2(1565)$	1562±13	0.70±0.14		56±11
.....				
sum				-7±64

- sum rules involving L photons

$$0 = \int_{s_0}^{\infty} ds \left[\frac{\tau_{TL}}{Q_1 Q_2} \right]_{Q_2^2=0}$$

$$0 = \int_{s_0}^{\infty} ds \frac{1}{(s + Q_1^2)^2} \left[\sigma_{\parallel} + \sigma_{LT} + \frac{(s + Q_1^2)}{Q_1 Q_2} \tau_{TL}^a \right]_{Q_2^2=0}$$

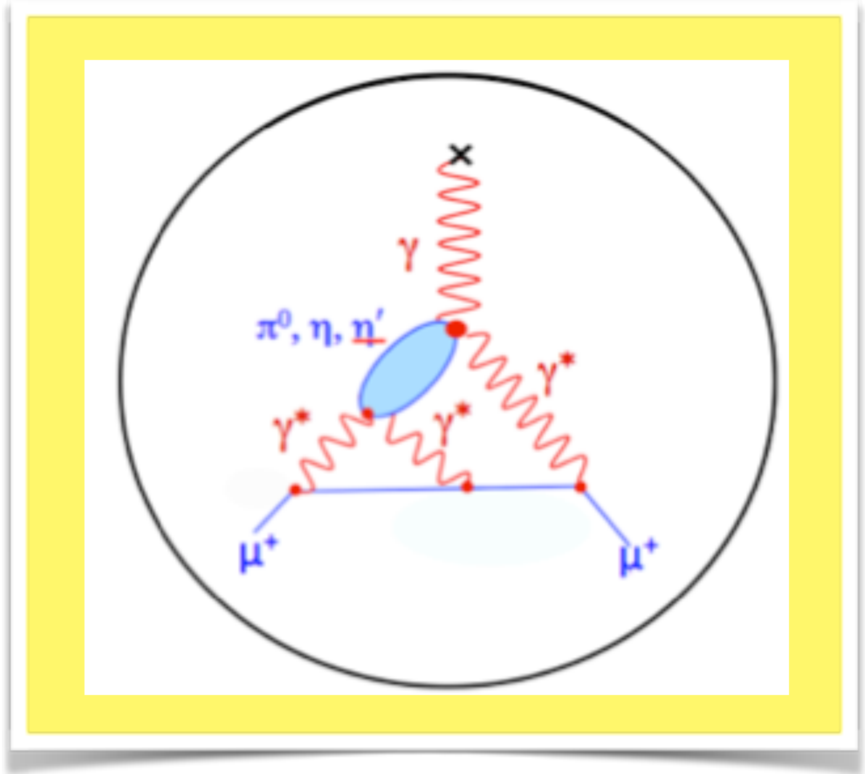
lowest few meson states saturate sum rules

Pascalutsa, Vdh (2010)

Pascalutsa, Pauk, Vdh (2012, 2014)

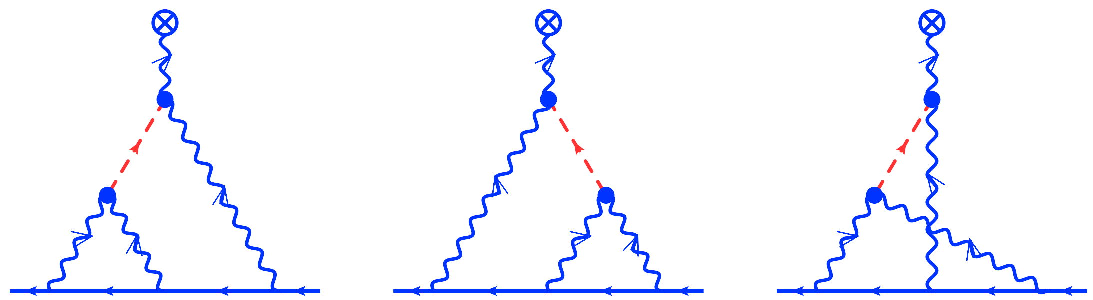
- Comparison lattice calculation for forward $\gamma^* \gamma^*$ scattering with dispersive estimates

talk V. Pascalutsa



how to estimate the HLbL contribution to a_μ ?

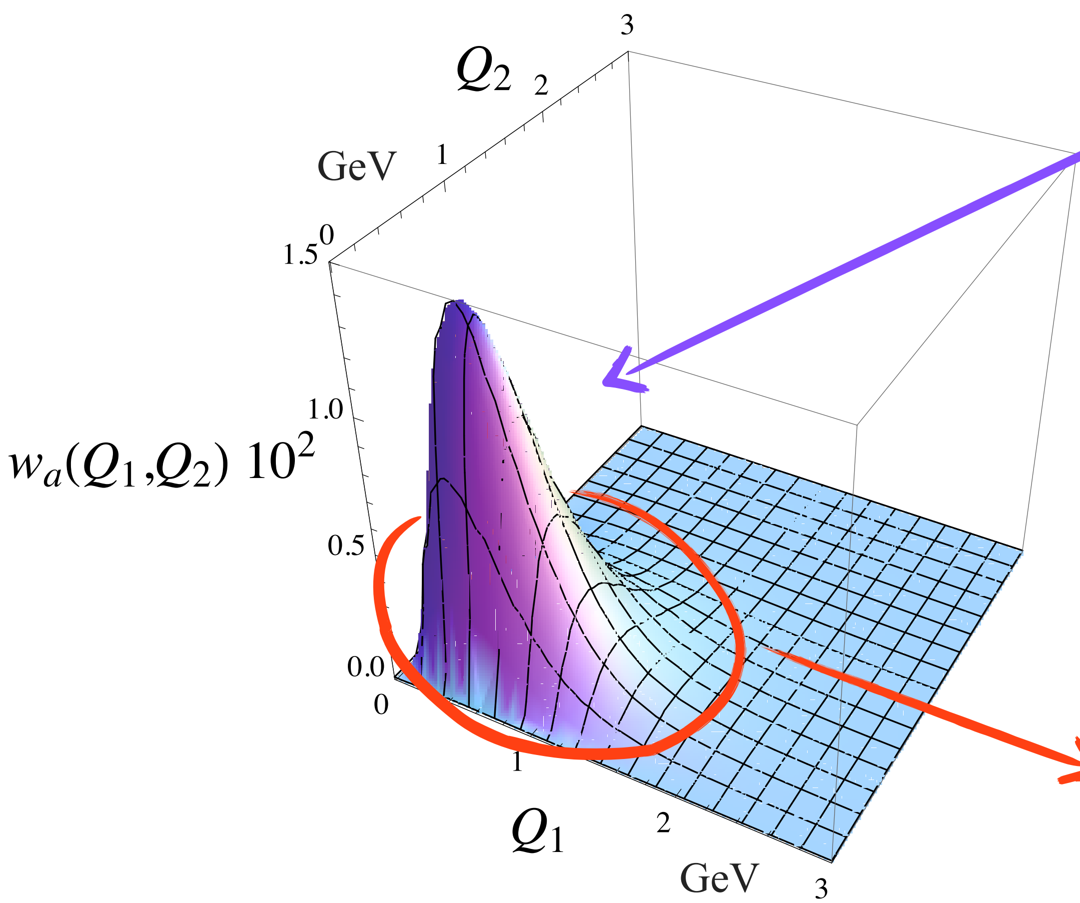
single meson contributions to a_μ



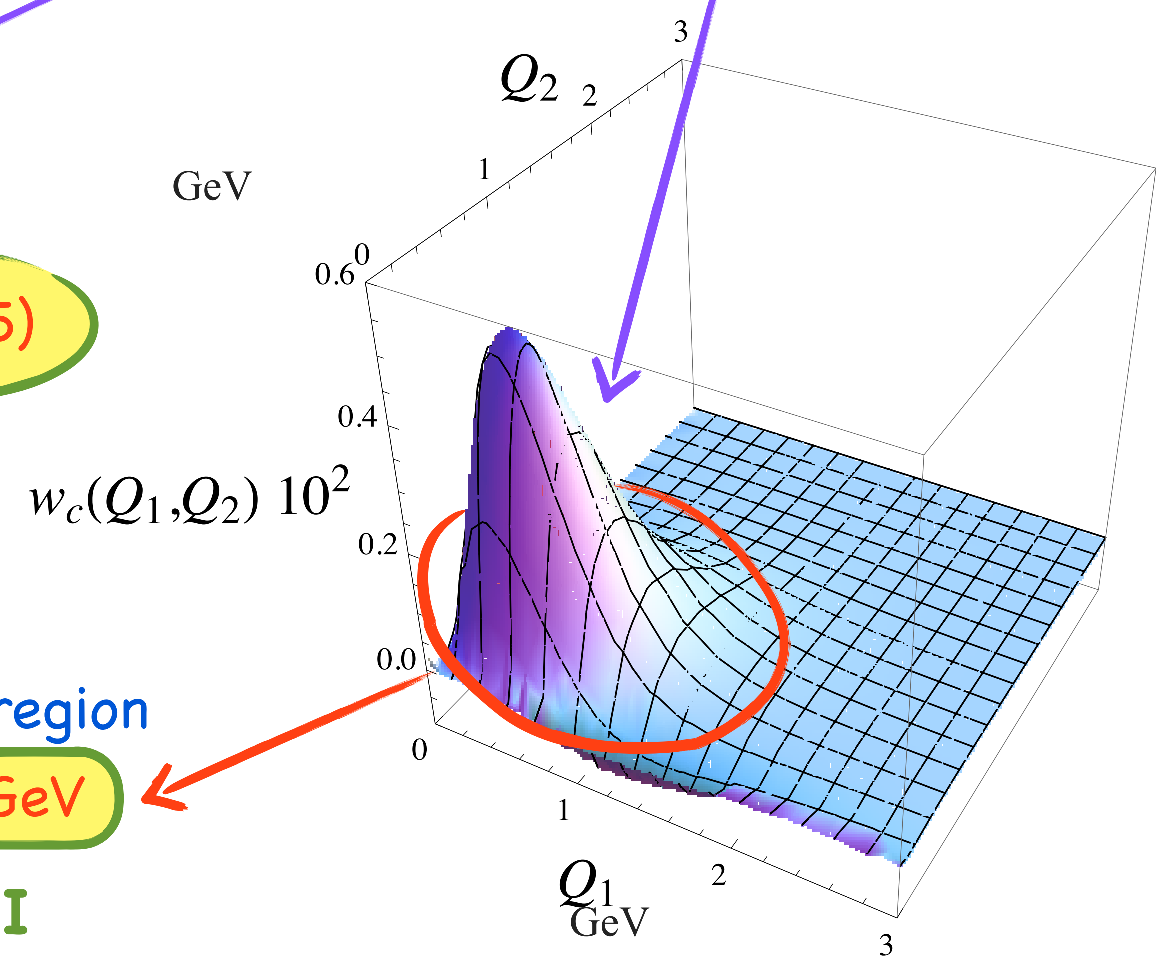
for π^0 : Knecht, Nyffeler (2002)

extended in many works

$$a_\mu^{LbL} = \frac{\alpha}{(2\pi)^2} \frac{\Lambda_{A1}^6 \Lambda_{A2}^6 \tilde{\Gamma}_{\gamma\gamma}(A)}{m\, m_A^5} \int \mathrm{d}Q_1 \int \mathrm{d}Q_2 \left[2 w_a(Q_1, Q_2) + w_c(Q_1, Q_2)\right]$$



f₁(1285)



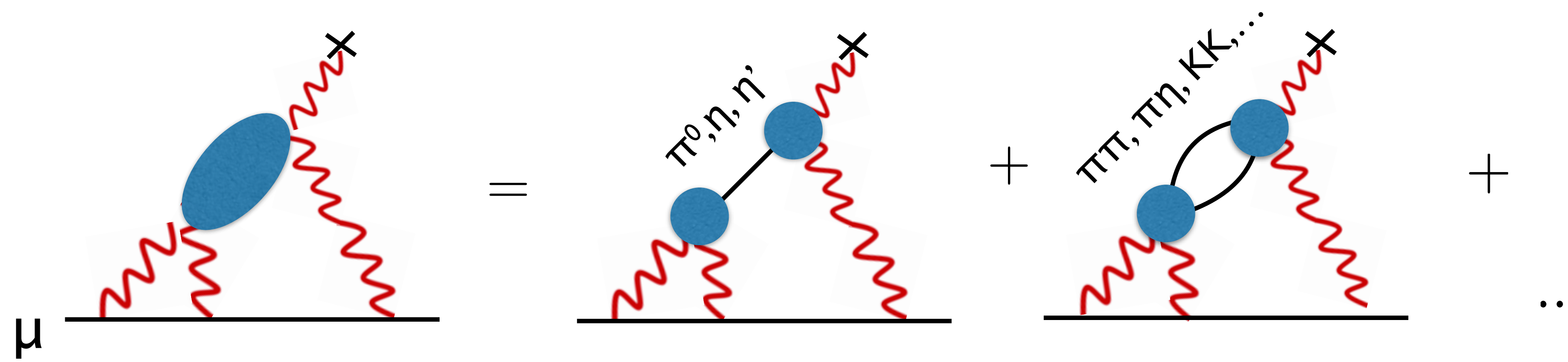
dominating region

$Q_1 \sim Q_2 \sim 1$ GeV

BES III

Pauk, Vdh (2013)

HLbL to a_μ : present status



Total HLbL

[a_μ in units 10^{-10}]

Authors	π^0, η, η'	$\pi\pi$, KK	scalars	axial vectors	quark loops	Total
BPaP(96)	8.5(1.3)	-1.9(1.3)	-0.68(0.20)	0.25(0.10)	2.1(03)	8.3(3.2)
HKS(96)	8.3(0.6)	-0.5(0.8)	—	0.17(0.17)	1.0(1.1)	9.0(1.5)
KnN(02)	8.3(1.2)	—	—	—	—	8.0(4.0)
MV(04)	11.4(1.0)	—	—	2.2(0.5)	—	13.6(2.5)
PdRV(09)	11.4(1.3)	-1.9(1.9)	-0.7(0.7)	1.5(1.0)	0.23	**10.5(2.6)**
N/JN(09)	9.9(1.6)	-1.9(1.3)	-0.7(0.2)	2.2(0.5)	2.1(0.3)	11.6(3.9)
J(15)	9.9(1.6)	-1.9(1.3)	-0.7(0.2)	**0.75(0.27)**	2.1(0.3)	**10.2(3.9)**

B=Bjnens, Pa=Pallante, P=Prades, H=Hayakawa, K=Kinoshita, S=Sanda, Kn=Knecht, N=Nyffeler, M=Melnikov, V=Vainshtein, dR=de Rafael, J=Jegerlehner

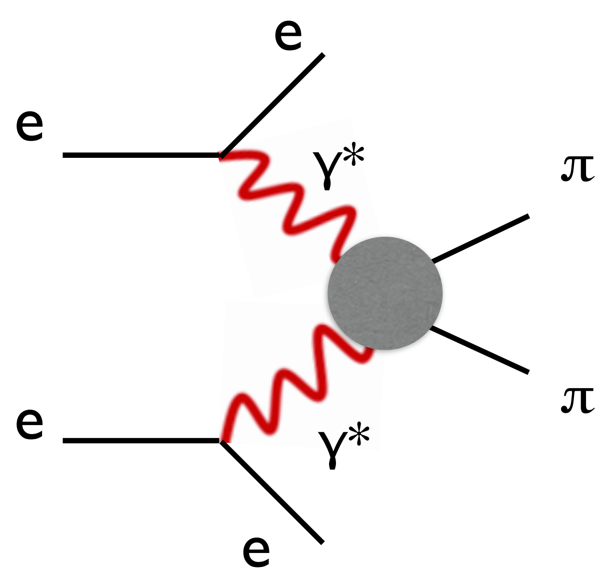
- Tensor meson contribution: ~ 0.1 x 10^{-10} (small relative to 1.6 x 10^{-10})

Pauk, Vdh (2013)
Danilkin, Vdh (2016)

- Improvements: include multi-meson channels in a data-driven / dispersive approach

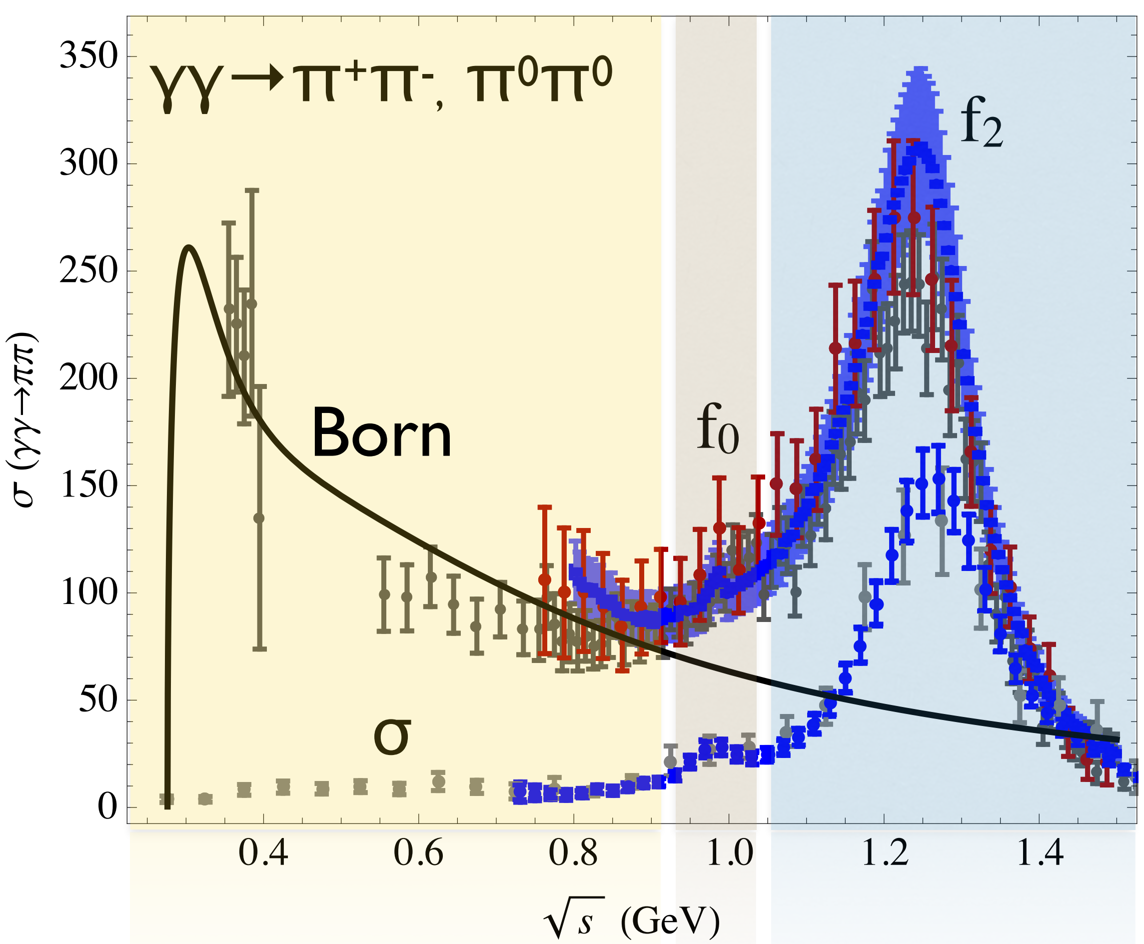
Improvements: multi-meson production

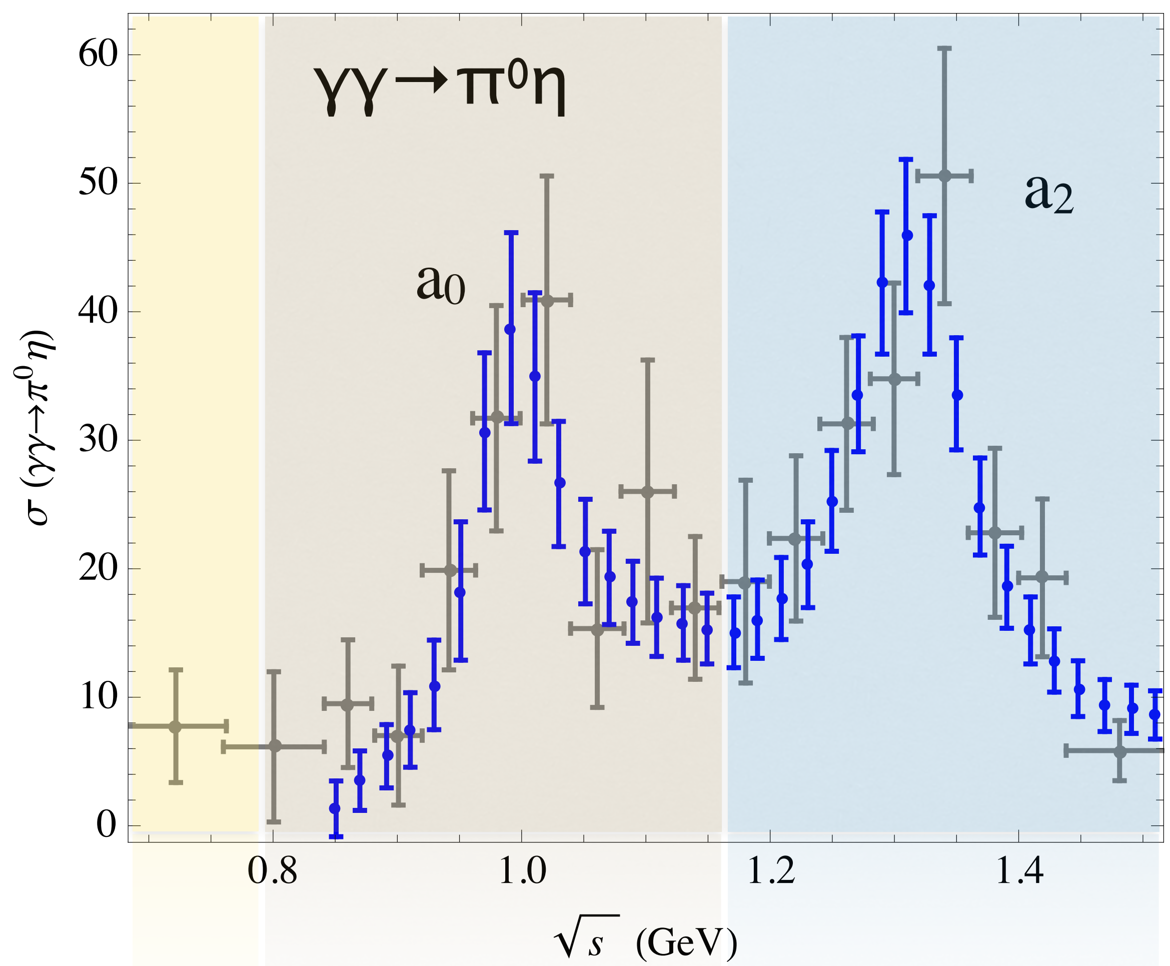
Observables in experiment $e^+e^- \to e^+e^-\pi\pi$



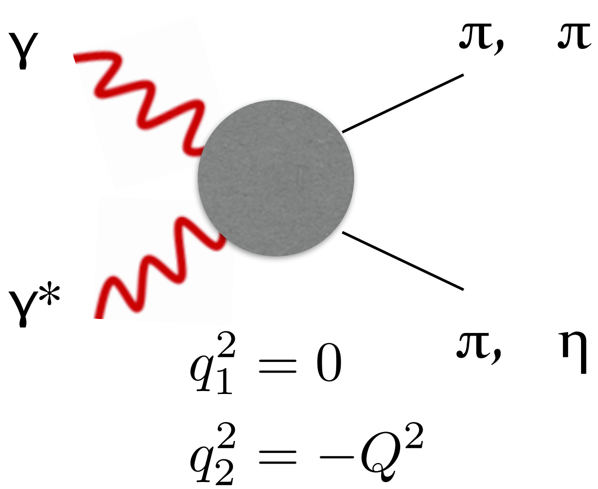
$$d\sigma = \frac{\alpha^2}{16\pi^4 Q_1^2 Q_2^2} \frac{2\sqrt{X}}{s(1-4m^2/s)^{1/2}} \cdot \frac{d^3\vec{p}_1'}{E_1'} \cdot \frac{d^3\vec{p}_2'}{E_2'} \times \left\{4\,\rho_1^{++}\,\rho_2^{++}\,\sigma_{TT} + \rho_1^{00}\,\rho_2^{00}\,\sigma_{LL} + 2\,\rho_1^{++}\,\rho_2^{00}\,\sigma_{TL} + \ldots\right\},$$

γγ→ππ, KK, ηη, πη (Belle: 07,08, 09,10, ..)
γγ*→ππ, πη (BESIII in progress)





Cross section



C=+1: $J^{PC}=0^{++}, 2^{++}, \ldots$

Helicity amplitudes

$$\langle \pi(p_1)\pi(p_2)|T|\gamma(q_1,\lambda_1)\gamma(q_2,\lambda_2)\rangle = (2\pi)^4\,\delta^{(4)}(p_1+p_2-q_1-q_2)\,H_{\lambda_1\lambda_2}$$

$$H_{\lambda_1\lambda_2} = H^{\mu\nu}\epsilon_\mu(\lambda_1)\,\epsilon_\nu(\lambda_2), \quad \lambda_1 = \pm 1,\ \lambda_2 = \pm 1, 0$$

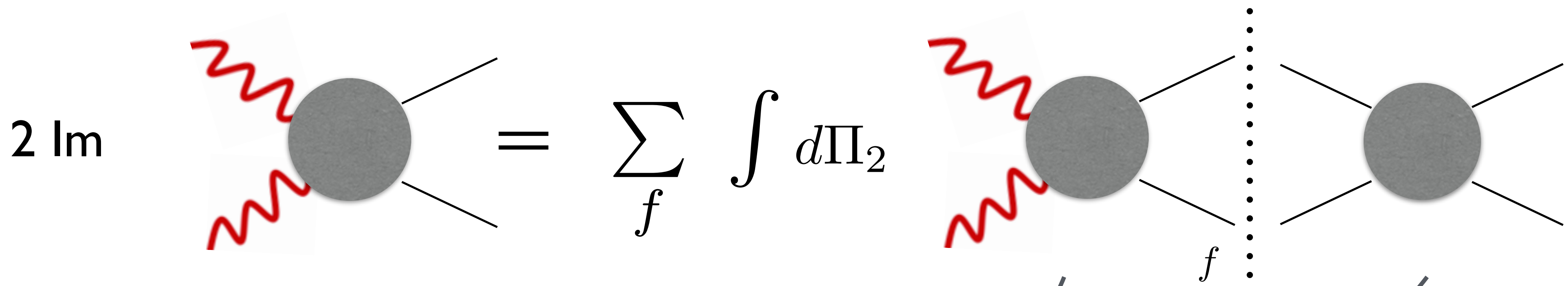
P symmetry: **6** → **3** independent amplitudes H_{++}, H_{+-}, H_{+0}

Cross sections

$$\sigma_{TT} = \pi\alpha^2 \frac{\rho(s)}{4\,(s+Q^2)} \int d\cos\theta\,\left(|H_{++}|^2 + |H_{+-}|^2\right)$$

$$\sigma_{TL} = \pi\alpha^2 \frac{\rho(s)}{2\,(s+Q^2)} \int d\cos\theta\,|H_{+0}|^2$$

Unitarity



Partial wave expansion

$$H_{\lambda_1\lambda_2}(s,t) = \sum_{J=0}^{\not\infty\; J_{max}=2} (2J+1)\, h_{J,\lambda_1\lambda_2}(s)\, d^J_{\lambda_1-\lambda_2,0}(\theta)$$

$$T(s,t) = \sum_{J=0}^{\not\infty\; J_{max}=2} (2J+1)\, t_J(s)\, P_J(\theta)$$

These “diagonalise unitarity” and contain resonance information

definite: J, λ_1, λ_2

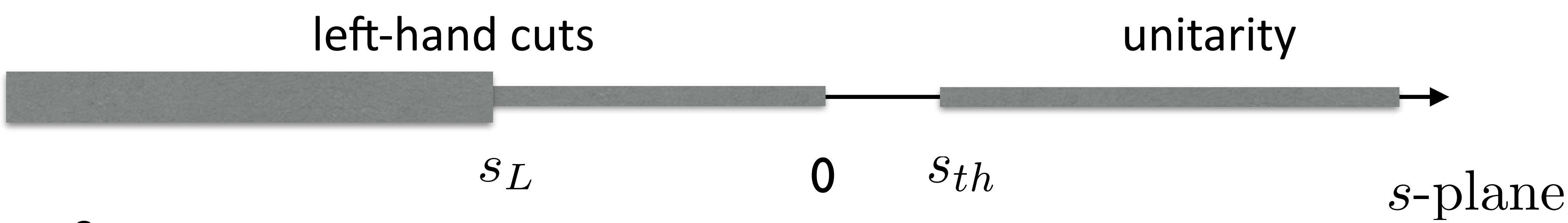
$$\mathrm{Im}\, h_{\gamma\gamma^*\to\pi\pi}(s) = \rho_{\pi\pi}\, h_{\gamma\gamma^*\to\pi\pi}\, t^*_{\pi\pi\to\pi\pi} + \rho_{KK}\, h_{\gamma\gamma^*\to KK}\, t^*_{KK\to\pi\pi} + \ldots$$

Dispersion relation

Morgan et al. (1998)
Garcia-Martin et al. (2010)
Moussallam (2013)

Write a dispersive representation for $\Omega^{-1}(s)(h(s) - h^{Born}(s))$

definite: *J*, λ_1, λ_2



Helicity - 0, s-wave

$$\begin{pmatrix} h_{++}(s) \\ k_{++}(s) \end{pmatrix} = \begin{pmatrix} h_{++}^{Born}(s) \\ k_{++}^{Born}(s) \end{pmatrix} + \Omega(s)\left[\begin{pmatrix} a \\ c \end{pmatrix} + \begin{pmatrix} b \\ d \end{pmatrix} s + \frac{s^2}{\pi}\int_{-\infty}^{s_L} \frac{ds'}{s'^2} \frac{\Omega(s')^{-1}}{s' - s} \begin{pmatrix} \mathrm{Im}\,\bar{h}_{++}(s') \\ \mathrm{Im}\,\bar{k}_{++}(s') \end{pmatrix} - \frac{s^2}{\pi}\int_{s_{th}}^{\infty} \frac{ds'}{s'^2} \frac{\mathrm{Im}\,\Omega(s')^{-1}}{s' - s} \begin{pmatrix} h_{++}^{Born}(s') \\ k_{++}^{Born}(s') \end{pmatrix}\right]$$

Coupled-channel Omnes function

$$\Omega(s) = \begin{pmatrix} \Omega_{\pi\pi\to\pi\pi} & \Omega_{\pi\pi\to K\bar{K}} \\ \Omega_{K\bar{K}\to\pi\pi} & \Omega_{K\bar{K}\to K\bar{K}} \end{pmatrix}$$

Unitarity $s \geq s_{th}$

$$\mathrm{Im}\,h(s) = h(s)\,\rho(s)\,t^*(s)$$
$$\mathrm{Im}\,\Omega(s) = \Omega(s)\,\rho(s)\,t^*(s)$$

What has been done so far?

$Q^2 = 0$	Approach	Inelasticity	Number of fitted parameters to $\sigma_{\gamma\gamma\to MM}$	Range of applicability
[Hoferichter et. al. 2011]	Roy-Steiner	$\pi\pi$	0	$\sqrt{s} < 0.98$ GeV
[Morgan et. al. 1998]	Disp, Omnes	$\pi\pi$	0	$\sqrt{s} \lesssim 0.6$ GeV
[Dai et. al. 2014]	Amplitude anal.	$\pi\pi$, KK	>20	$\sqrt{s} < 1.5$ GeV
[Garcia-Martin et.al. 2010]	Disp, Omnes	$\pi\pi$, KK	6	$\sqrt{s} < 1.3$ GeV
[Current work]	Disp, Omnes	$\pi\pi$, KK $\pi\eta$, KK	0	$\sqrt{s} < 1.4$ GeV
$Q^2 \neq 0$				
[Moussallam 2013]	Disp, Omnes	$\pi\pi$, J=0	0	$\sqrt{s} \lesssim 0.8$ GeV
[Colangelo et.al. 2017]	Roy-Steiner	$\pi\pi$, J=0	0	$\sqrt{s} \lesssim 0.8$ GeV
[Current work]	Disp, Omnes	$\pi\pi$, KK, J=0,2 $\pi\eta$, KK	0	$\sqrt{s} < 1.4$ GeV

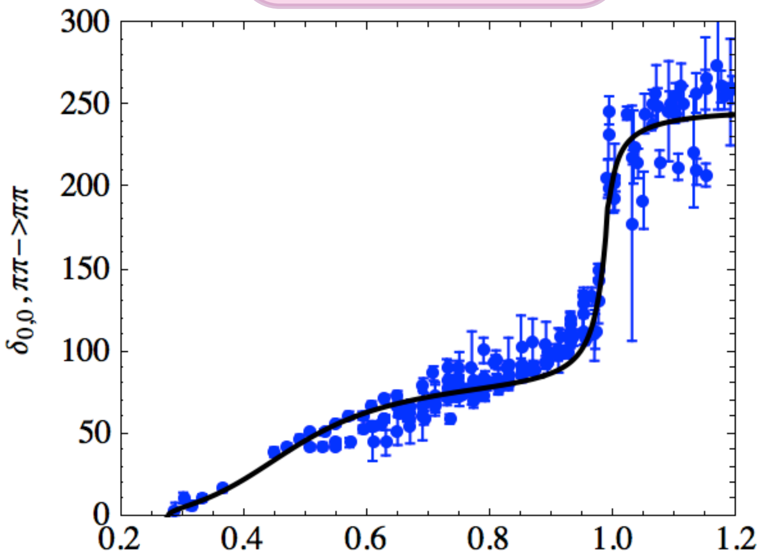
Only dispersive analyses are shown

Omnes function I=0, {ππ, KK}

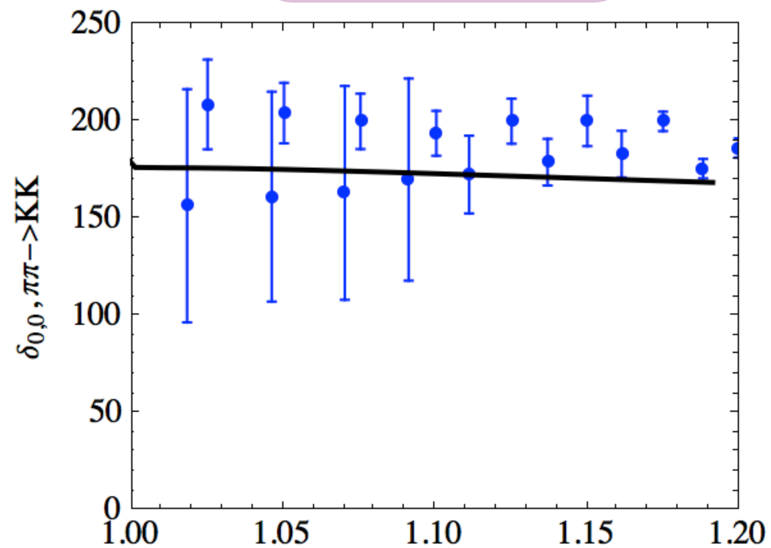
Coupled channel Omnes

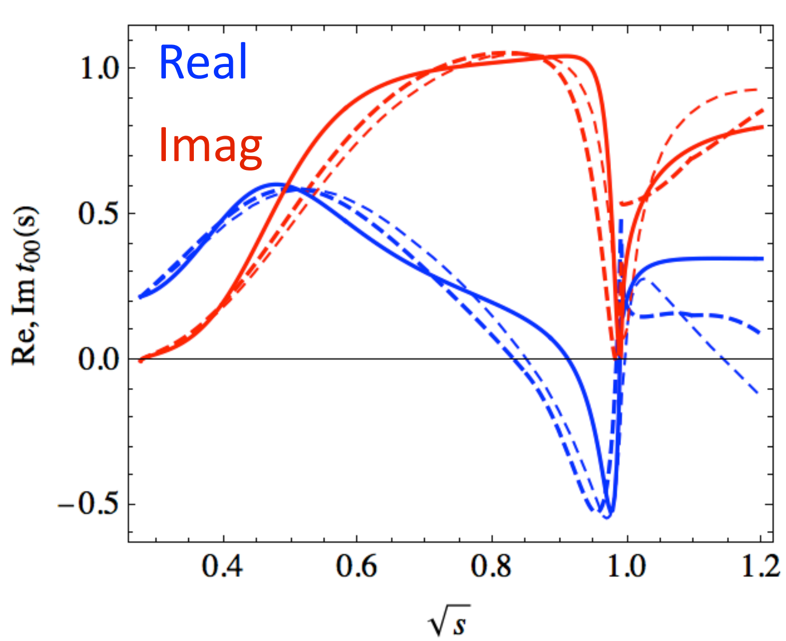
$$\Omega(s) = \begin{pmatrix} \Omega_{\pi\pi\to\pi\pi} & \Omega_{\pi\pi\to K\bar{K}} \\ \Omega_{K\bar{K}\to\pi\pi} & \Omega_{K\bar{K}\to K\bar{K}} \end{pmatrix}$$

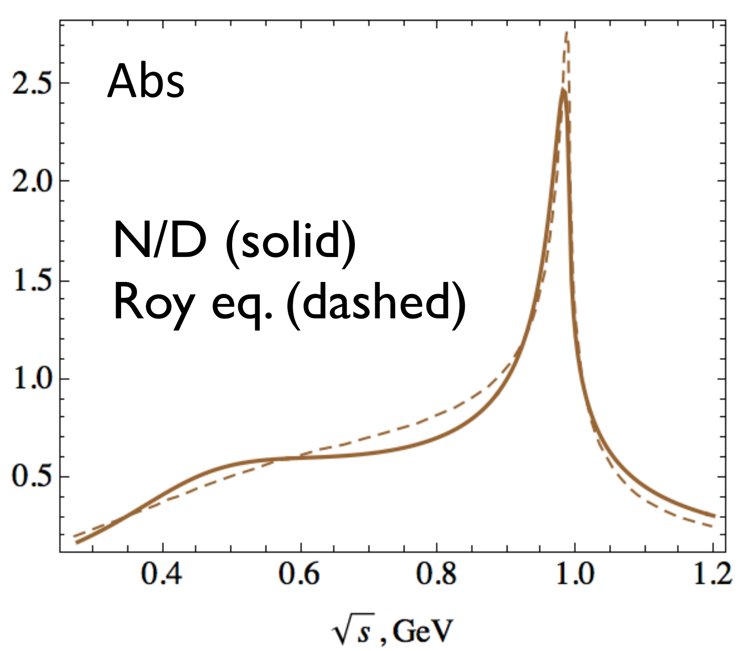
ππ → ππ



ππ → KK







Danilkin, Gil, Lutz (2011, 2013)

Bounded p.w. amplitudes and Omnes at large energies

$$T(s) = \Omega(s)\, N(s)$$

$$N(s) = U(s) + \frac{s}{\pi}\int_R \frac{ds'}{s'}\frac{\rho(s')N(s')(U(s)-U(s'))}{s'-s}$$

$$\Omega^{-1}(s) = 1 - \frac{s}{\pi}\int_R \frac{ds'}{s'}\frac{\rho(s')N(s')}{s'-s}$$

$$U(s) = \sum_k C_k\, \xi(s)^k$$

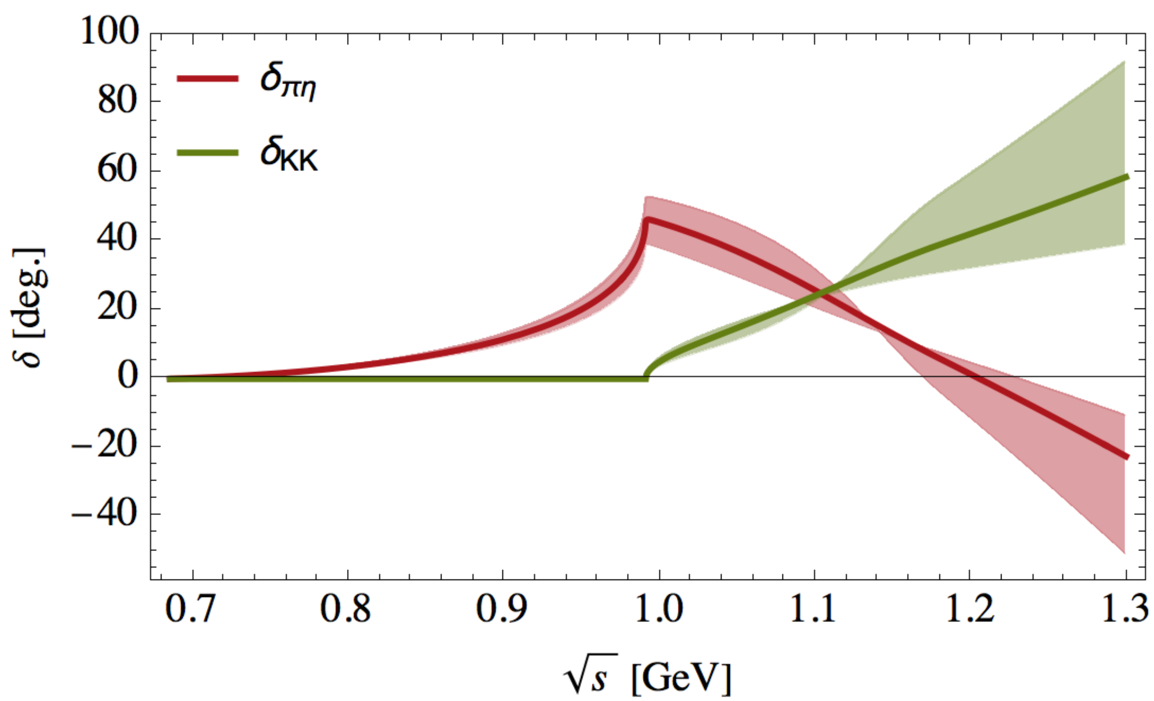
C_k **fitted** to exp. **data** and Roy Eq. solutions

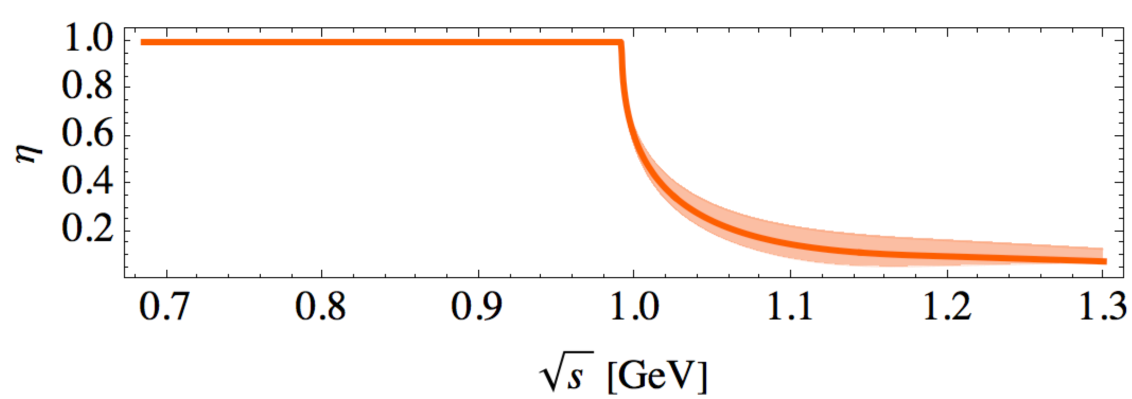
Omnes function I=1, {πη, KK}

Coupled channel Omnes

$$\Omega(s) = \begin{pmatrix} \Omega_{\pi\eta\to\pi\eta} & \Omega_{\pi\eta\to K\bar{K}} \\ \Omega_{K\bar{K}\to\pi\eta} & \Omega_{K\bar{K}\to K\bar{K}} \end{pmatrix}$$

$\pi^0\eta \to \pi^0\eta$





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$$T(s) = \Omega(s)\,N(s)$$

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$$\Omega^{-1}(s) = 1 - \frac{s}{\pi}\int_R \frac{ds'}{s'}\frac{\rho(s')N(s')}{s'-s}$$

$$U(s) = \sum_k C_k\,\xi(s)^k$$

C_k **matched** to SU(3) **ChPT** at threshold

Danilkin, Gil, Lutz (2011, 2013)

Left-hand cuts

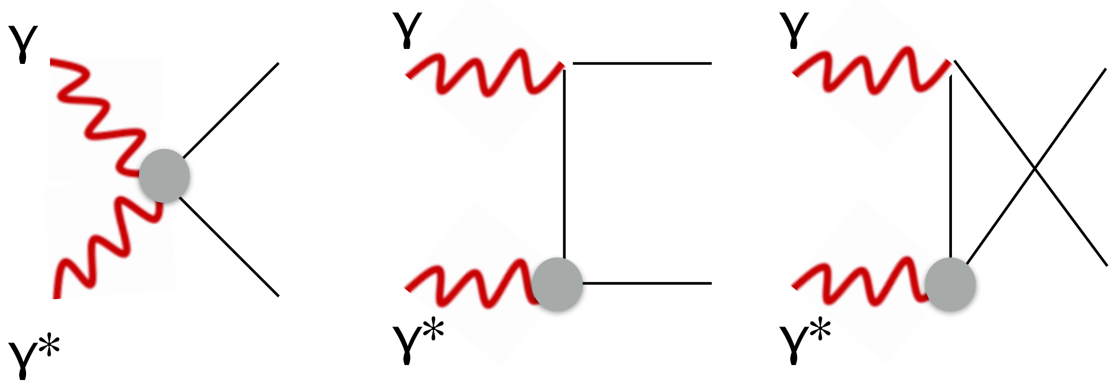
Morgan et al. (1998)

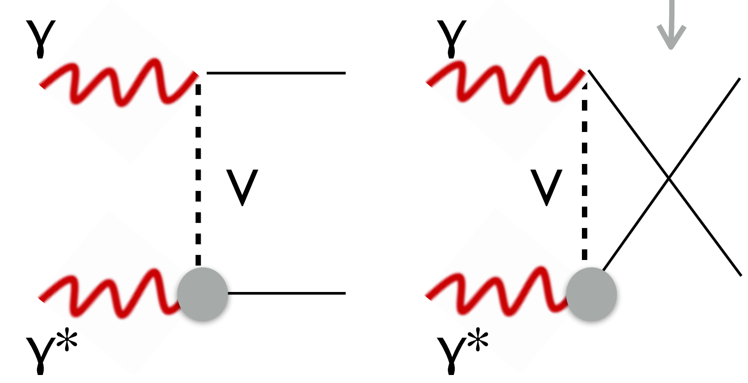
Moussallam (2013)

Dispersive integral for J=0

$$\begin{pmatrix} h_{++}(s) \\ k_{++}(s) \end{pmatrix} = \begin{pmatrix} h_{++}^{Born}(s) \\ k_{++}^{Born}(s) \end{pmatrix} + \Omega(s)\left[\begin{pmatrix} a \\ c \end{pmatrix} + \begin{pmatrix} b \\ d \end{pmatrix} s + \frac{s^2}{\pi}\int_{-\infty}^{s_L} \frac{ds'}{s'^2}\frac{\Omega(s')^{-1}}{s'-s}\begin{pmatrix} \mathrm{Im}\,\bar{h}_{++}(s') \\ \mathrm{Im}\,\bar{k}_{++}(s') \end{pmatrix} - \frac{s^2}{\pi}\int_{s_{th}}^{\infty} \frac{ds'}{s'^2}\frac{\mathrm{Im}\,\Omega(s')^{-1}}{s'-s}\begin{pmatrix} h_{++}^{Born}(s') \\ k_{++}^{Born}(s') \end{pmatrix}\right]$$

Scalar QED (pion pole contribution)





Fearing, Scherer (1998)

Colangelo et al. (2015)

Vertex ππγ*

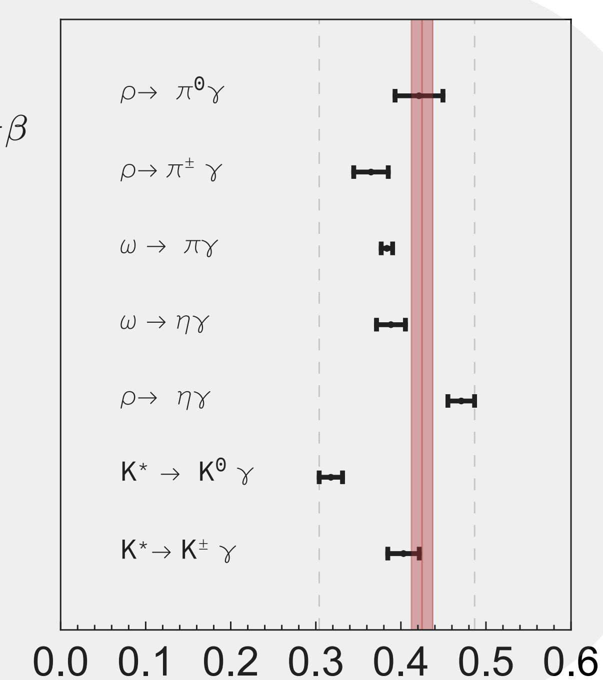
$$\langle \pi^+ | j_\mu(0) | \pi^+(p') \rangle = (p+p')_\mu \, F_\pi(Q^2)$$

$$F_\pi(Q^2) = \frac{1}{1+Q^2/M_\rho^2}$$

$$\mathcal{L} = e\, C_V\, \epsilon_{\mu\nu\alpha\beta}\, F^{\mu\nu}\, \partial^\alpha \phi\, V^\beta$$

$$F_{\pi\omega}(Q^2) = \frac{1}{1+Q^2/M_\rho^2}$$

$$F_{\pi\rho}(Q^2) = \frac{1}{1+Q^2/M_\omega^2}$$



Subtraction constants

Dispersive integral for J=0

$$\begin{pmatrix} h_{++}(s) \\ k_{++}(s) \end{pmatrix} = \begin{pmatrix} h^{Born}_{++}(s) \\ k^{Born}_{++}(s) \end{pmatrix} + \Omega(s)\left[\begin{pmatrix} a \\ c \end{pmatrix} + \begin{pmatrix} b \\ d \end{pmatrix} s + \frac{s^2}{\pi}\int_{-\infty}^{s_L} \frac{ds'}{s'^2}\,\frac{\Omega(s')^{-1}}{s'-s}\begin{pmatrix} \mathrm{Im}\,\bar{h}_{++}(s') \\ \mathrm{Im}\,\bar{k}_{++}(s') \end{pmatrix} - \frac{s^2}{\pi}\int_{s_{th}}^{\infty} \frac{ds'}{s'^2}\,\frac{\mathrm{Im}\,\Omega(s')^{-1}}{s'-s}\begin{pmatrix} h^{Born}_{++}(s') \\ k^{Born}_{++}(s') \end{pmatrix}\right]$$

Soft photon limit (q_1=0)

$$H_{\lambda_1\lambda_2} \to H^{Born}_{\lambda_1\lambda_2}$$

$$s = -Q^2,\ t = u = m_\pi^2$$

For space like photons: generalized polarizabilities

$$\pm\frac{2\alpha}{m_\pi}\frac{H^n_{+\pm}}{s+Q^2} = (\alpha_1 \mp \beta_1)_{\pi^0} + \ldots$$

$$\pm\frac{2\alpha}{m_\pi}\frac{(H^c_{+\pm} - H^{Born}_{+\pm})}{s+Q^2} = (\alpha_1 \mp \beta_1)_{\pi^+} +$$

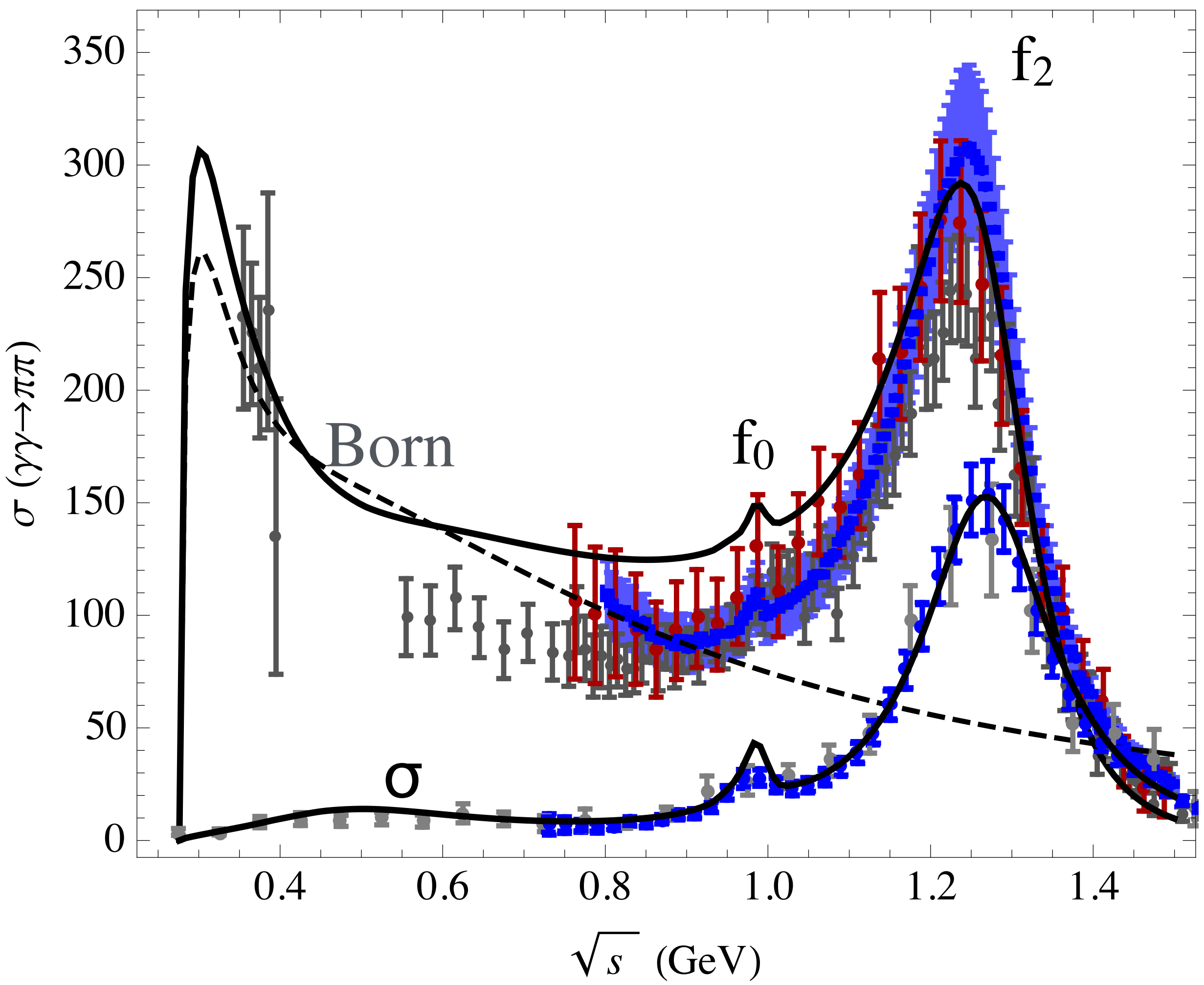
COMPASS data on $(\alpha_1\text{-}\beta_1)_{\pi^+}$
(future Hall D (JLab) experiment)

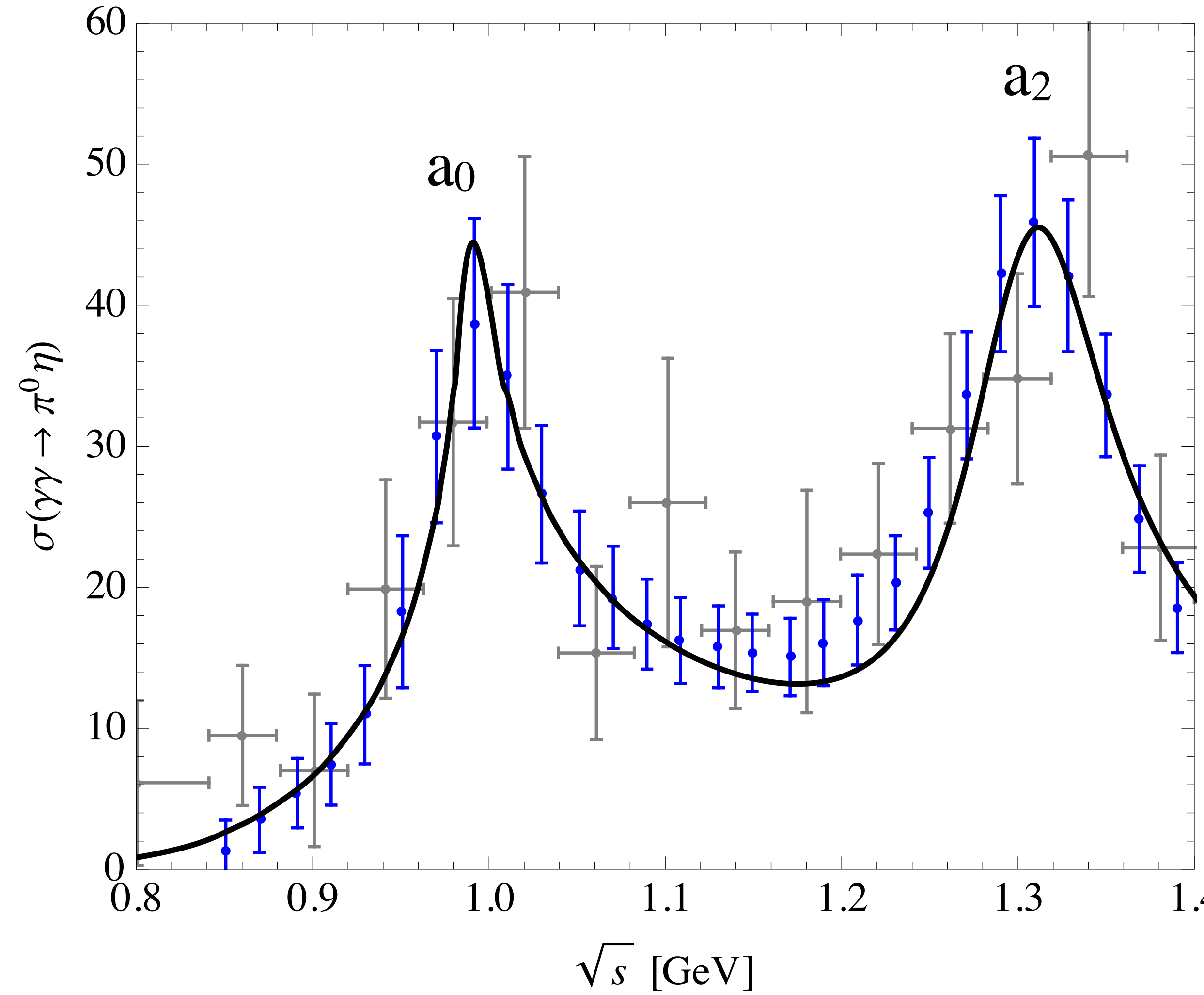
multi-meson production in $\gamma\gamma$ collisions

$\gamma\gamma \to \pi^+\pi^-, \pi^0\pi^0$

$Q^2 = 0$ GeV^2

$\gamma\gamma \to \pi^0\eta$





Coupled-channel dispersive treatment of $f_0(980)$ and $a_0(980)$ is **crucial**

$f_2(1270)$ described dispersively through Omnes function

$a_2(1320)$ described as a Breit Wigner resonance

$\pi^0\eta$: Danilkin, Deineka, Vdh (2017)

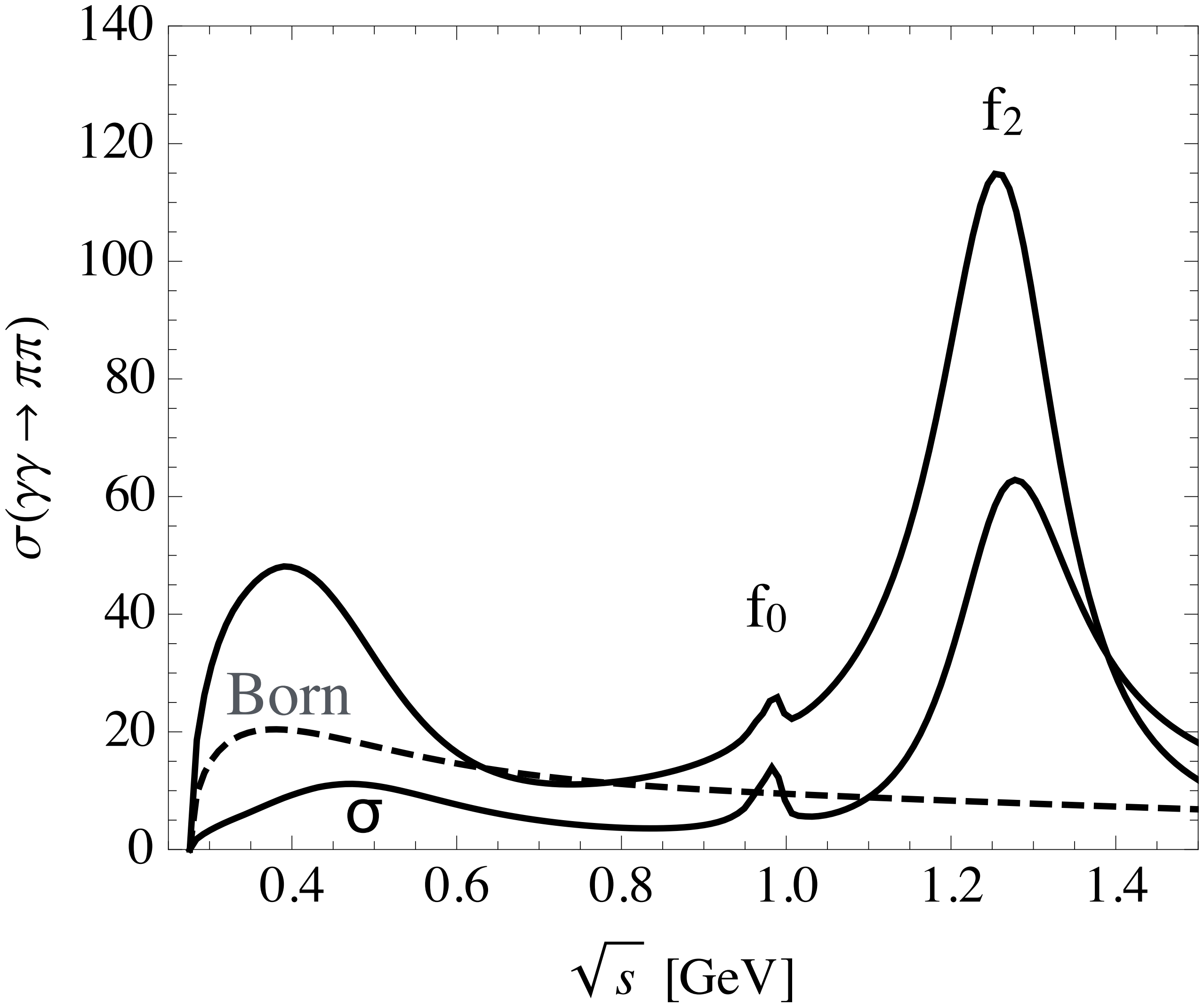
$\pi\pi$: Danilkin, Vdh (in progress)

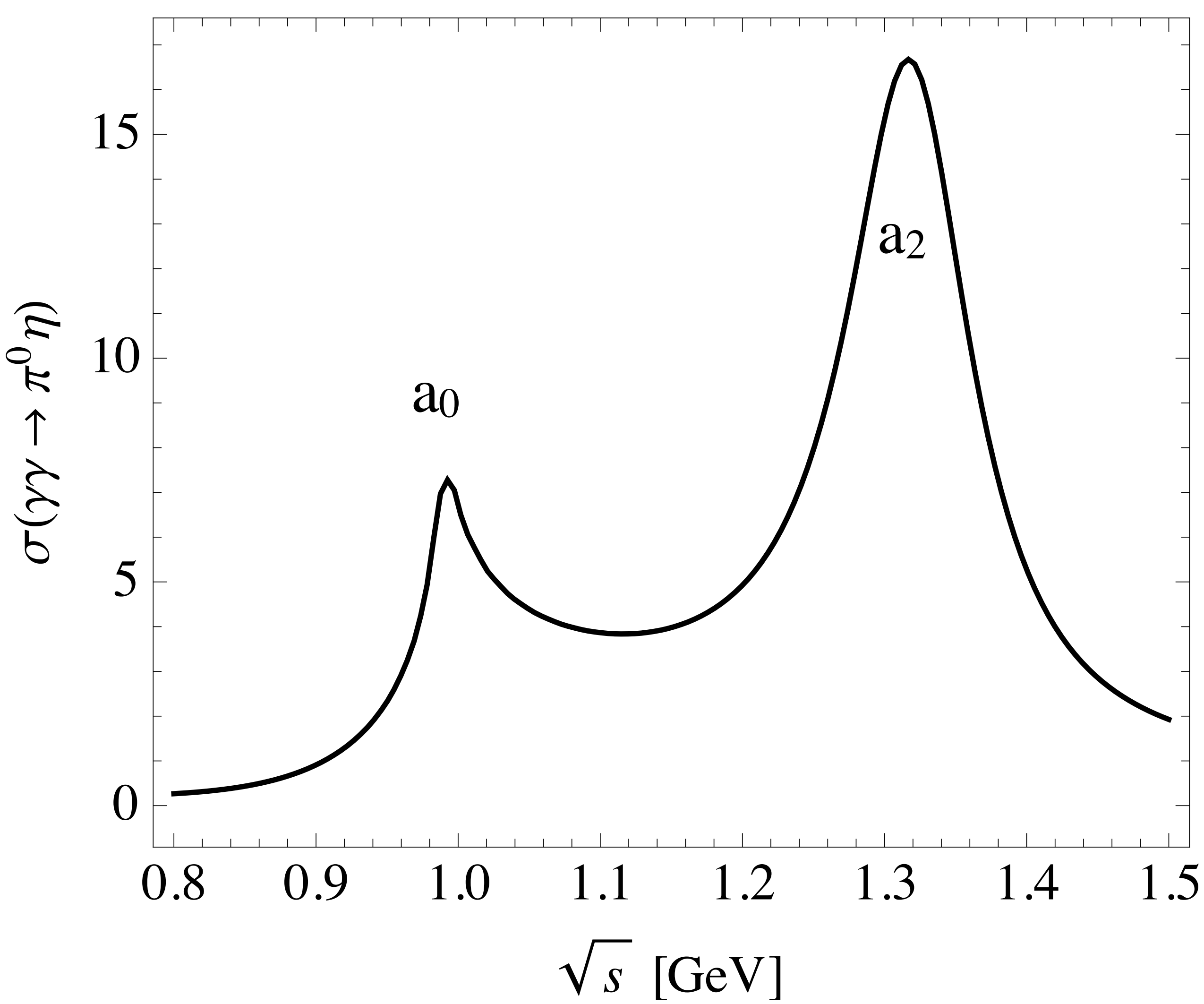
multi-meson production in $\gamma^*\gamma$ collisions

$\gamma^*\gamma \to \pi^+\pi^-, \pi^0\pi^0$

$Q^2 = 0.5$ GeV^2

$\gamma^*\gamma \to \pi^0\eta$

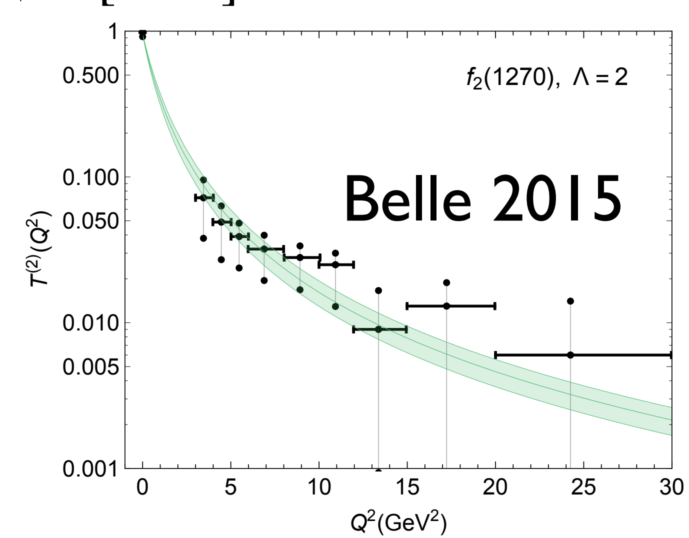




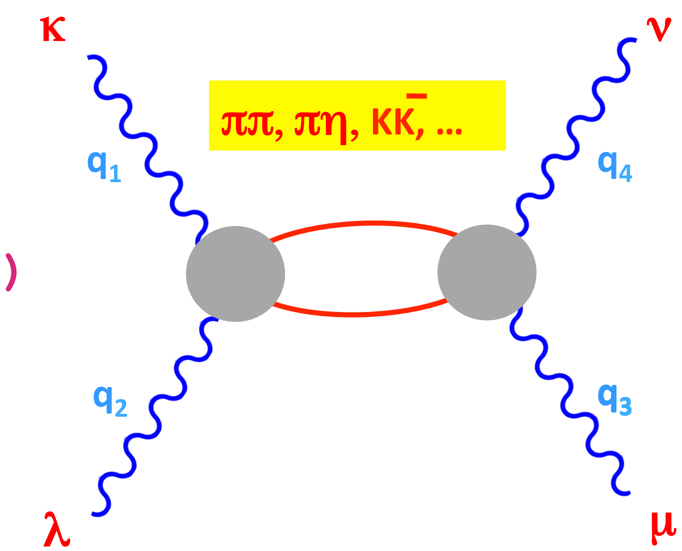
Coupled-channel dispersive treatment for $f_0(980)$ and $a_0(980)$

$f_2(1270)$, $a_2(1320)$ as Breit Wigner resonance, TFF taken from Belle data

Single tagged BES-III data for $\pi^+\pi^-$, $\pi^0\pi^0$
in range 0.1 GeV^2 < Q^2 < 3 GeV^2 under analysis

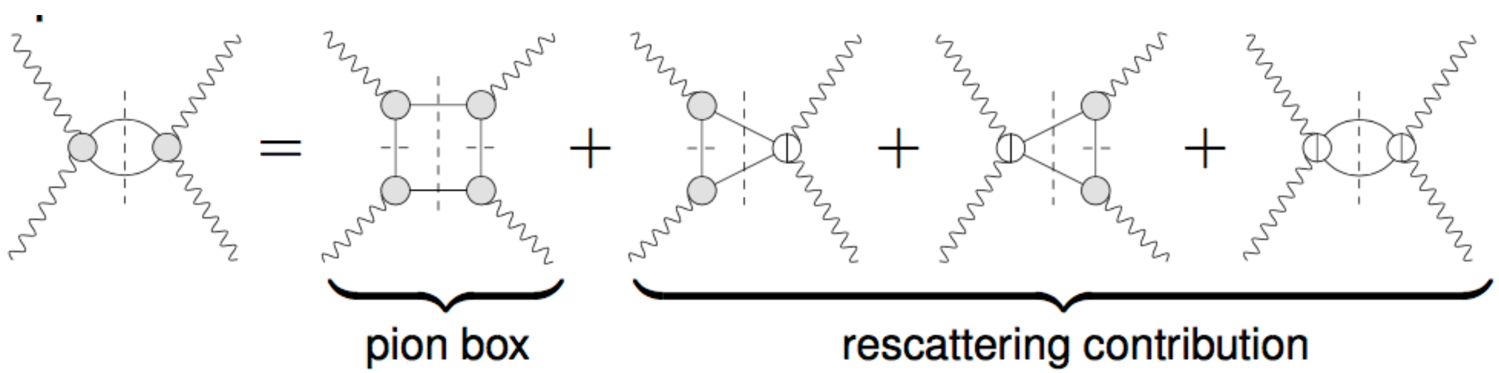


multi-meson contributions a_μ



- pioneering dispersive analyses for ππ loop contribution to a_μ

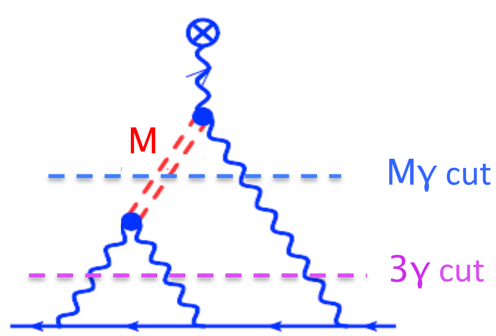
  Colangelo, Hoferichter, Procura, Stoffer (2014,2015, 2017)



$a_\mu^{\pi\text{-box}} = (-1.59 \pm 0.02) \times 10^{-10}$ $a_\mu^{\text{s-wave } \pi\pi} = (-0.8 \pm 0.1) \times 10^{-10}$

contribution so far only for pion-pole left hand cut

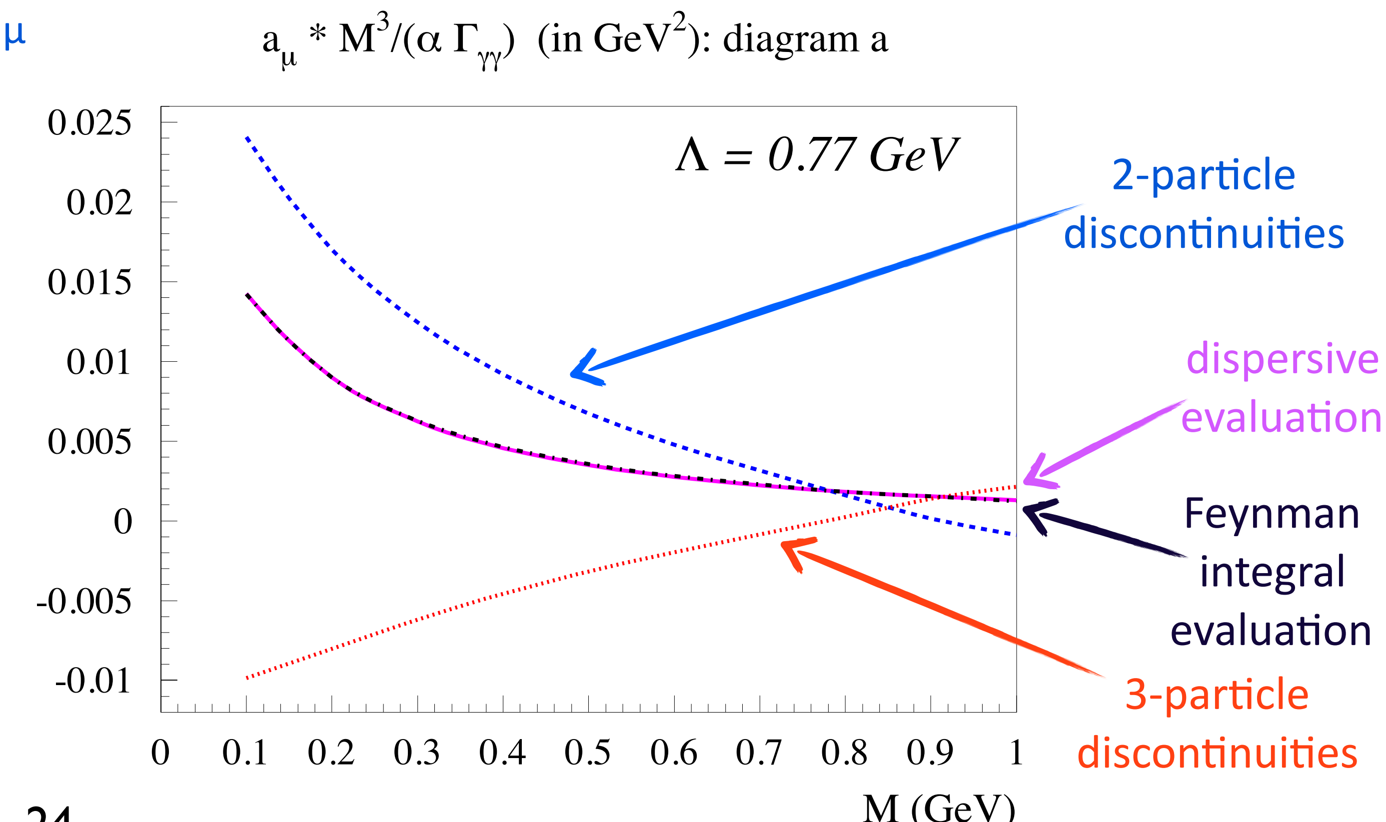
- dispersive analysis for muon Pauli FF -> a_μ



Proof of principle calculation for pseudo-scalar meson (M) pole contributions to a_μ :

e.g. $a_\mu^{\pi 0} = 5.7 \times 10^{-10}$

Pauk, Vdh (2014)



Summary and outlook

- new a_μ Fermilab and J-Parc experiments ongoing:

  aim: factor 4 improvement in experimental value

- complementary experimental program (BESIII, Belle II) ongoing as input for the hadronic contributions to the HVP and HLbL contributions to a_μ talk Ch. Redmer

- new dispersion relation frameworks for HLbL to a_μ :
  -> require close collaboration with experiment / validation (spacelike, timelike, meson decays)

  aim: data driven approach also in HLbL

- Theory goal: realistic error estimate on a_μ
  reduce to 2×10^{-10} (20 % of HLbL) to match accuracy of forthcoming experiments
  -> Muon (g-2) Theory Initiative

  Aim of concerted effort is to allow for a conclusive statement on the present 4σ deviation in a_μ between experiment and SM prediction !