universitätbonn

bctp Bethe Center for Theoretical Physics

Project A7: Precision Computations in Hadron Physics

Herbi K. Dreiner,
together with Bastian Kubis and Cai-Dian Lü

PKU, Aug. 29th, 2017

Three Topics

- Bounds on R-parity violating supersymmetry from $B^0 - \bar{B}^0$ mixing. (H. Dreiner)

- Search for new physics in hadronic B-decays, $\Delta S = 2$ transistions. (Cai-Dian Lü)

- Pseudoscalar transition form factors and $(g-2)_\mu$ (B. Kubis)

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Detailed talk by Zeren Simon Wang: 31/8

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Detailed talk by Faisal Munir: 30/8

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$B^0 - \bar{B}^0$ Mixing and RPV SUSY

RPV-MSSM superpotential

$$W_{\not{R}_p} = \mu_i H_u L_i + \frac{1}{2}\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \frac{1}{2}\lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k \quad (1)$$

- Create effective operators contributing to $B^0 - \bar{B}^0$ mixing

$B^0 - \bar{B}^0$ Mixing and RPV SUSY

Effective Lagrangian:

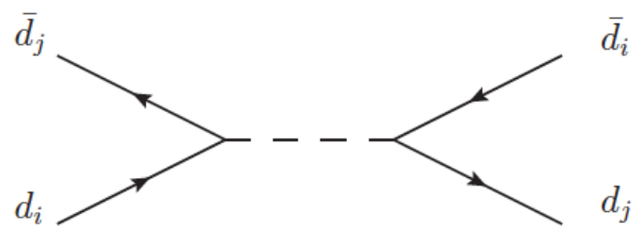
$$\mathcal{L}_{\text{eff}} = \sum_i C_i O_i + h.c.$$

C_i: Wilson coefficients. O_i: dim-6 operators.

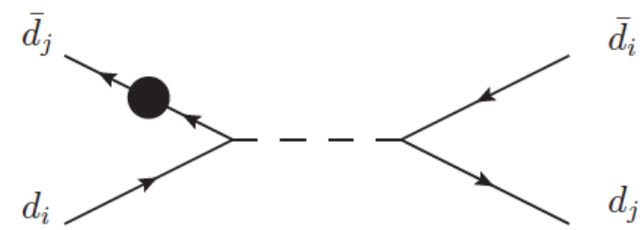
$$O_1 = (\bar{d}_j \gamma^\mu P_L d_i)(\bar{d}_j \gamma_\mu P_L d_i), \qquad \tilde{O}_1 = (\bar{d}_j \gamma^\mu P_R d_i)(\bar{d}_j \gamma_\mu P_R d_i),$$
$$O_2 = (\bar{d}_j P_L d_i)(\bar{d}_j P_L d_i), \qquad \tilde{O}_2 = (\bar{d}_j P_R d_i)(\bar{d}_j P_R d_i),$$
$$O_3 = (\bar{d}_j^a P_L d_i^b)(\bar{d}_j^b P_L d_i^a), \qquad \tilde{O}_3 = (\bar{d}_j^a P_R d_i^b)(\bar{d}_j^b P_R d_i^a),$$
$$O_4 = (\bar{d}_j P_L d_i)(\bar{d}_j P_R d_i), \qquad O_5 = (\bar{d}_j^a P_L d_i^b)(\bar{d}_j^b P_R d_i^a).$$

$i, j = d, s, b$ down-type quarks, $a, b = 1, 2, 3$ three colors.

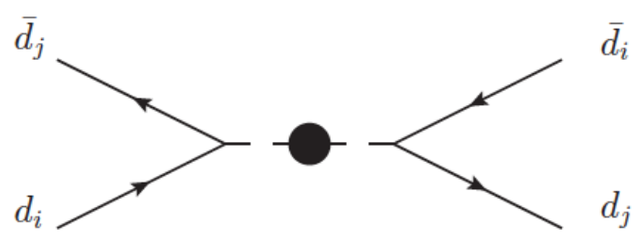
$B^0 - \bar{B}^0$ Mixing and RPV SUSY



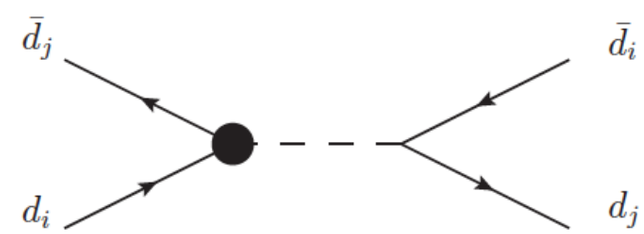
(a) Tree-level Feynman diagram



(b) Quark self-energies corrections

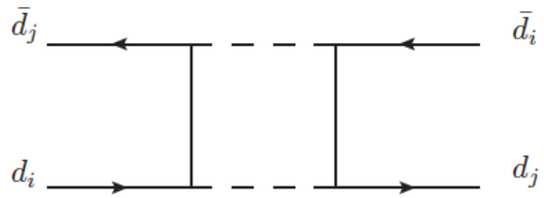


(c) Scalar self-energies

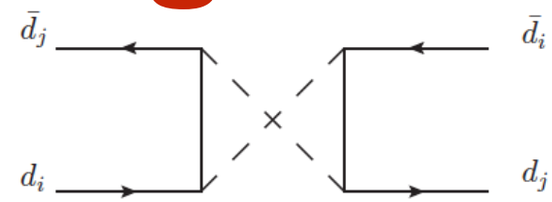


(d) Vertex corrections

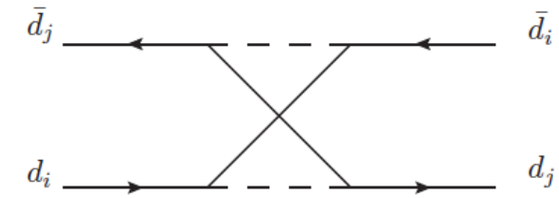
$B^0 - \bar{B}^0$ Mixing and RPV SUSY



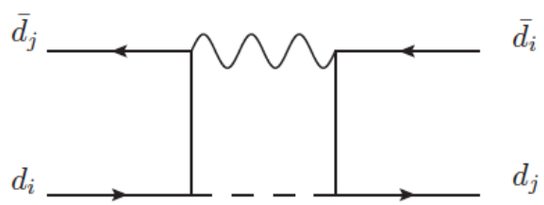
(a) S/F/S/F
straight box



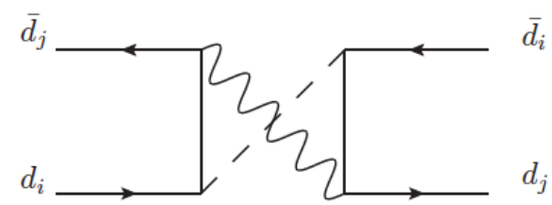
(b) S/F/S/F
scalar-cross box



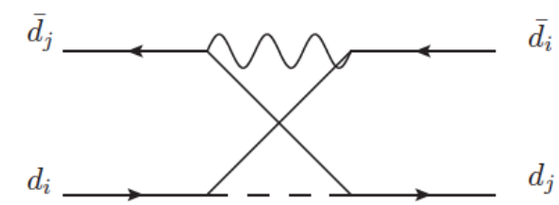
(c) S/F/S/F
fermion-cross box



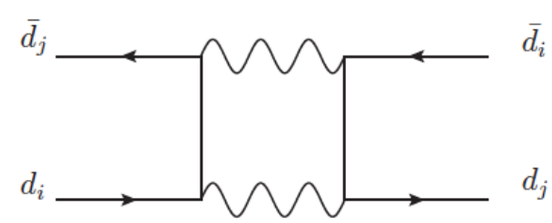
(d) V/F/S/F
straight box



(e) V/F/S/F
cross boxes



(f) V/F/S/F
fermion-cross box



(g) V/F/V/F
straight box

S: Scalar, F: Fermion, V: Vector

Search for new physics in hadronic B decays - ΔS =2 transition (talk by F. Munir)

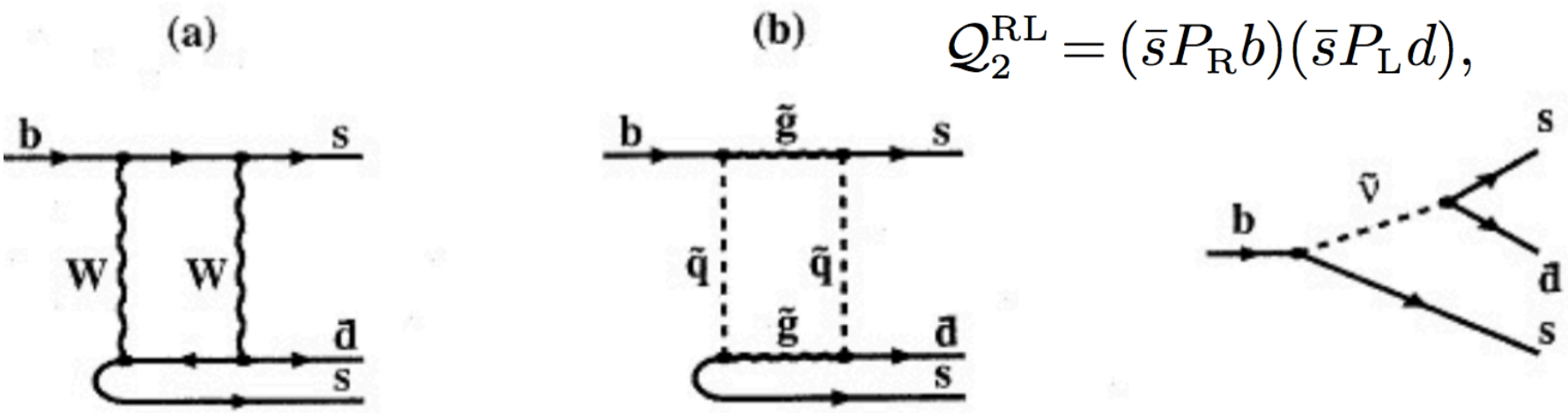
CD Lu, F. Munir, Q. Qin, Chin. Phys. C41 (2017) 053106

$$\mathcal{Q}_1^{VLL} = (\bar{s}\gamma_\mu P_L b)(\bar{s}\gamma^\mu P_L d),$$
$$\mathcal{Q}_1^{VRR} = (\bar{s}\gamma_\mu P_R b)(\bar{s}\gamma^\mu P_R d),$$
$$\mathcal{Q}_1^{LR} = (\bar{s}\gamma_\mu P_L b)(\bar{s}\gamma^\mu P_R d),$$
$$\mathcal{Q}_2^{LR} = (\bar{s}P_L b)(\bar{s}P_R d),$$
$$\mathcal{Q}_1^{RL} = (\bar{s}\gamma_\mu P_R b)(\bar{s}\gamma^\mu P_L d),$$
$$\mathcal{Q}_2^{RL} = (\bar{s}P_R b)(\bar{s}P_L d),$$

SM BRs: ~ 10^{-14},

New physics can reach 10^{-6}

Randall-Sundrum model ~ 10^{-10}



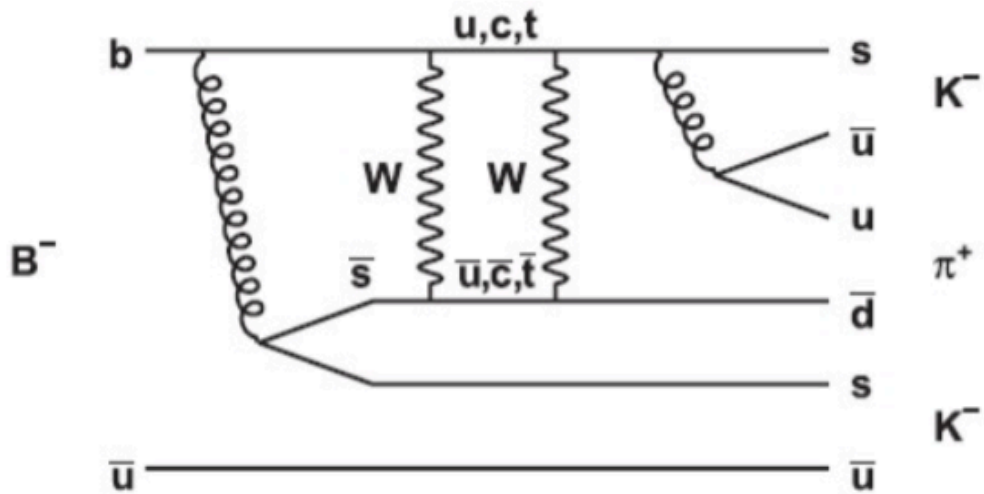
$b \to s s \bar{d}$ transition (a) SM, (b) MSSM, (c) MSSM with R-parity violating coupling

Experimental search starting from OPAL @ LEP, phys. Lett. B 476 (2000) 233, later searched also by Belle/Babar

BABAR collaboration, Phys. Rev. D 78 (2008) 091102 [arXiv:0808.0900]

A search for the decay $B^- \to K^-K^-\pi^+$, Using a sample of $(467 \pm 5) \times 10^6$ $B\overline{B}$ pairs collected with the BABAR detector.

LHCb, Phys.Lett. B765 (2017) 307-316



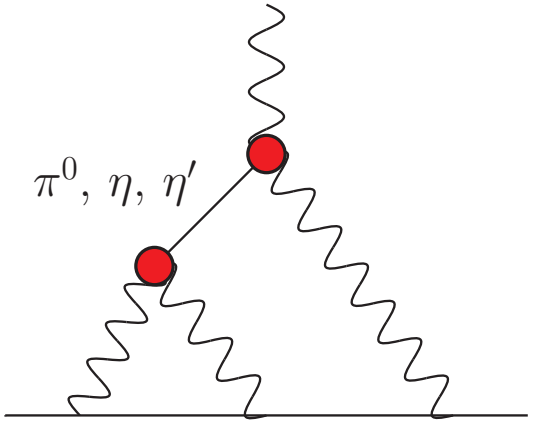
Similar channel $B^- \to \pi^-\pi^-K^+$

Result : No evidence for these decays was found and a upper limit was set as

$$\mathcal{B}(B^+ \to K^+K^+\pi^-) < 1.1 \times 10^{-8} \qquad \mathcal{B}(B^+ \to \pi^+\pi^+K^-) < 4.6 \times 10^{-8}.$$

Pseudoscalar transition form factors and $(g-2)_\mu$

- largest individual HLbL contribution:
  pseudoscalar pole terms
  singly / doubly virtual form factors
  $F_{P\gamma\gamma^*}(q^2,0)$ and $F_{P\gamma^*\gamma^*}(q_1^2,q_2^2)$



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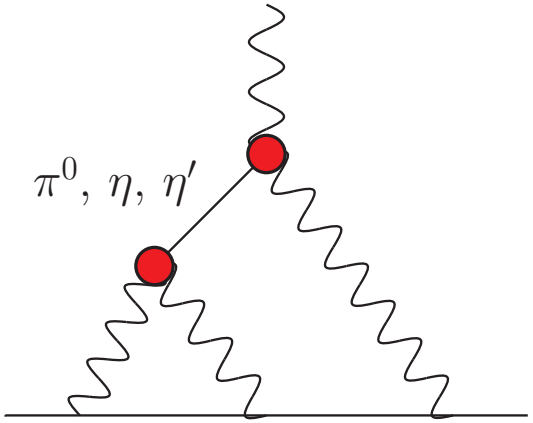

- normalisation fixed by Wess–Zumino–Witten anomaly, e.g.:

$$F_{\pi^0\gamma\gamma}(0,0) = \frac{e^2}{4\pi^2 F_\pi}$$

F_π: pion decay constant $\longrightarrow$ measured at 1.5% level PrimEx 2011

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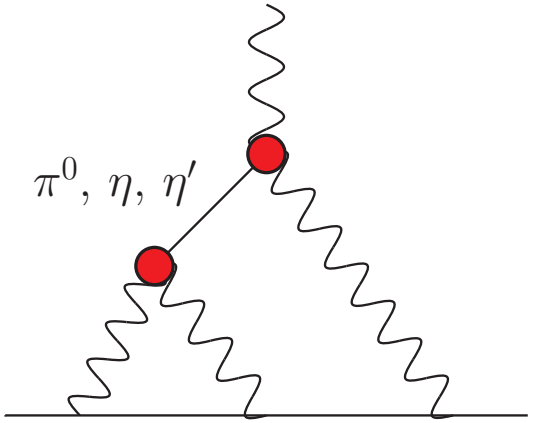

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- q_i^2-dependence: often modelled by vector-meson dominance
  $\longrightarrow$ what can we learn from analyticity and unitarity constraints?
  $\longrightarrow$ what experimental input sharpens these constraints?

Dispersive analysis of $\pi^0/\eta^{(\prime)} \to \gamma^*\gamma^*$

- isospin decomposition:

$$F_{\pi^0\gamma^*\gamma^*}(q_1^2, q_2^2) = F_{vs}(q_1^2, q_2^2) + F_{vs}(q_2^2, q_1^2)$$

$$F_{\eta^{(\prime)}\gamma^*\gamma^*}(q_1^2, q_2^2) = F_{vv}(q_1^2, q_2^2) + F_{ss}(q_2^2, q_1^2)$$

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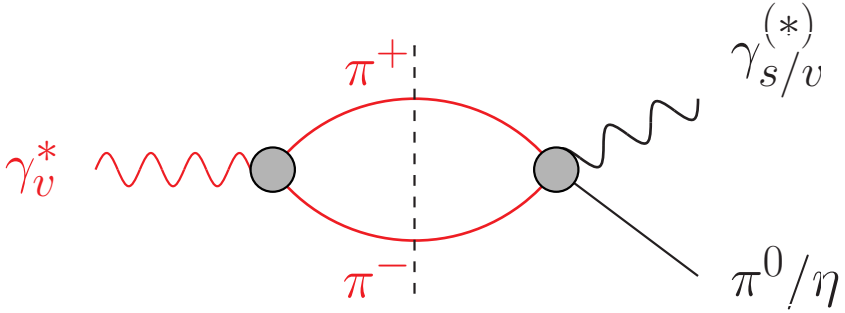
- analyse the leading hadronic intermediate states:

Hanhart et al. 2013, Hoferichter et al. 2014



▷ isovector photon: 2 pions

$\propto$ pion vector form factor $\times$ $\gamma^{(*)} \to 3\pi$ / $\eta^{(\prime)} \to \pi\pi\gamma^{(*)}$

all determined in terms of pion–pion P-wave phase shift

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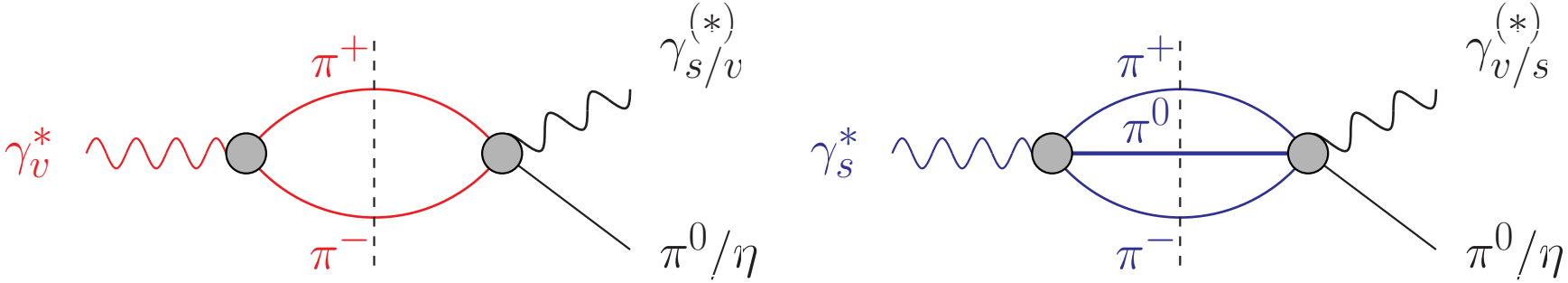

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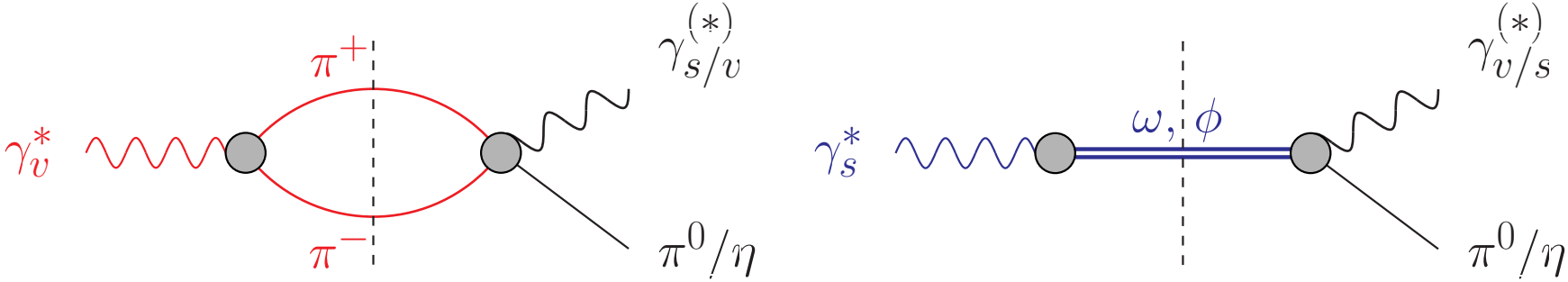

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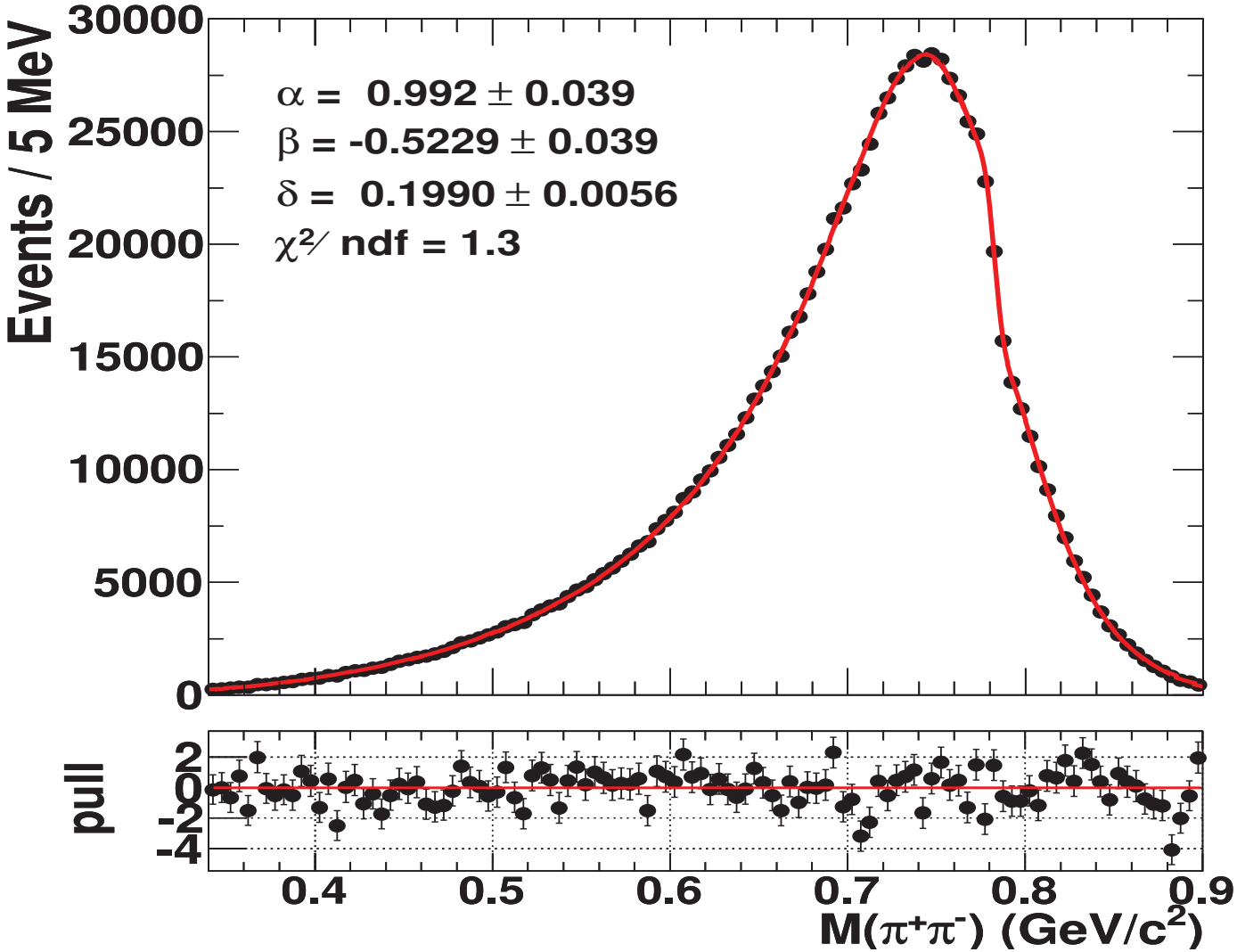
▷ isoscalar photon: 3 pions $\longrightarrow$ dominated by narrow ω, ϕ

$\leftrightarrow \omega/\phi$ transition form factors; very small for the η

New BESIII data on $\eta' \to \pi^+\pi^-\gamma$



BESIII preliminary, Fang 2015

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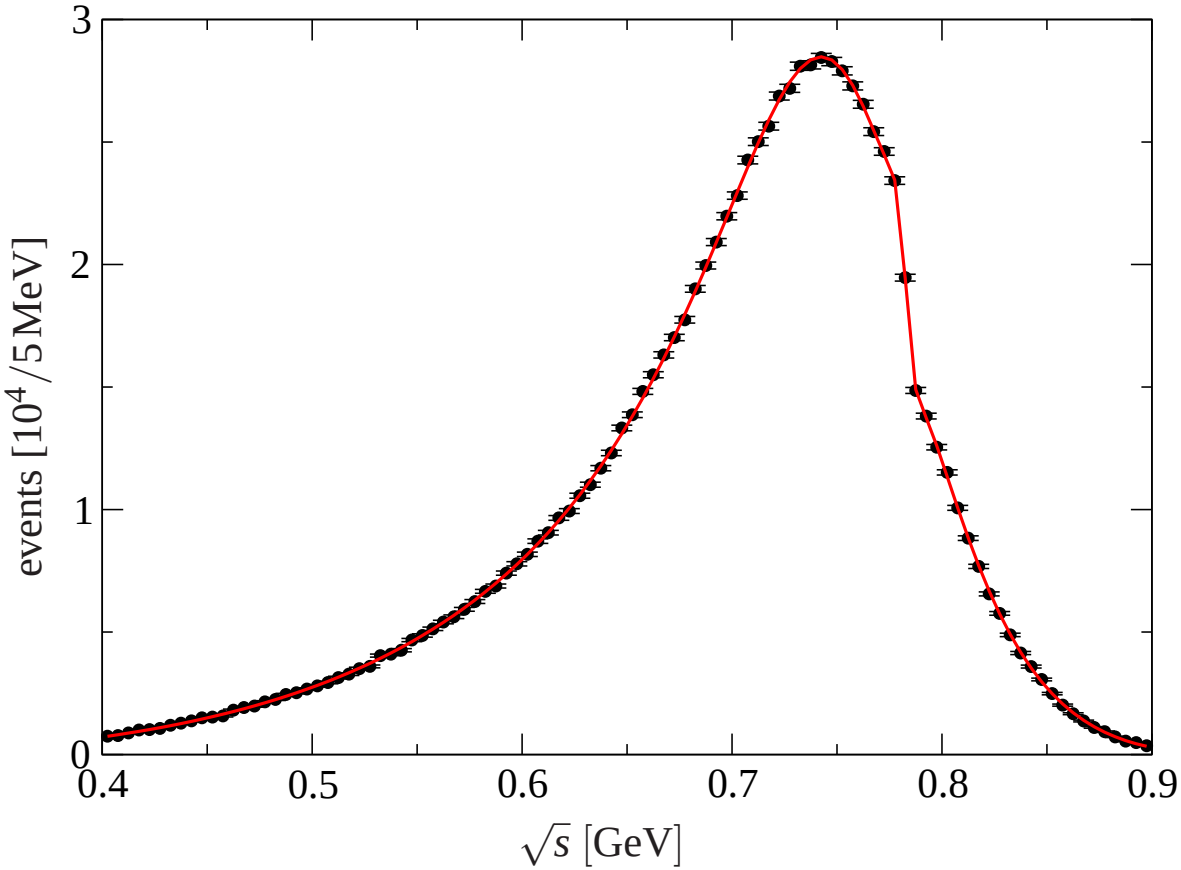


fit to pseudodata after BESIII preliminary

- fit form $$\left[A(1+\alpha t+\beta t^2)+\frac{\kappa}{m_\omega^2-t-im_\omega\Gamma_\omega}\right]\times\Omega(t)$$

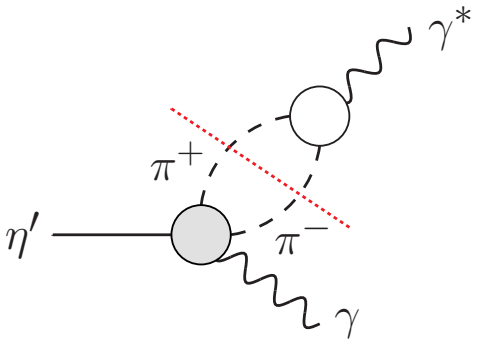
  $\longrightarrow$ curvature $\propto \beta t^2$ essential

  $\longrightarrow$ even ρ–ω mixing clearly visible

Hanhart et al. 2017

Prediction for η' transition form factor

- isovector: combine high-precision data on $\eta' \to \pi^+\pi^-\gamma$ and $e^+e^- \to \pi^+\pi^-$
- isoscalar: VMD, couplings fixed from $\eta' \to \omega\gamma$ and $\phi \to \eta'\gamma$



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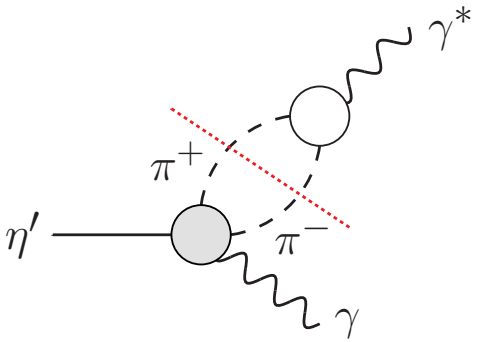
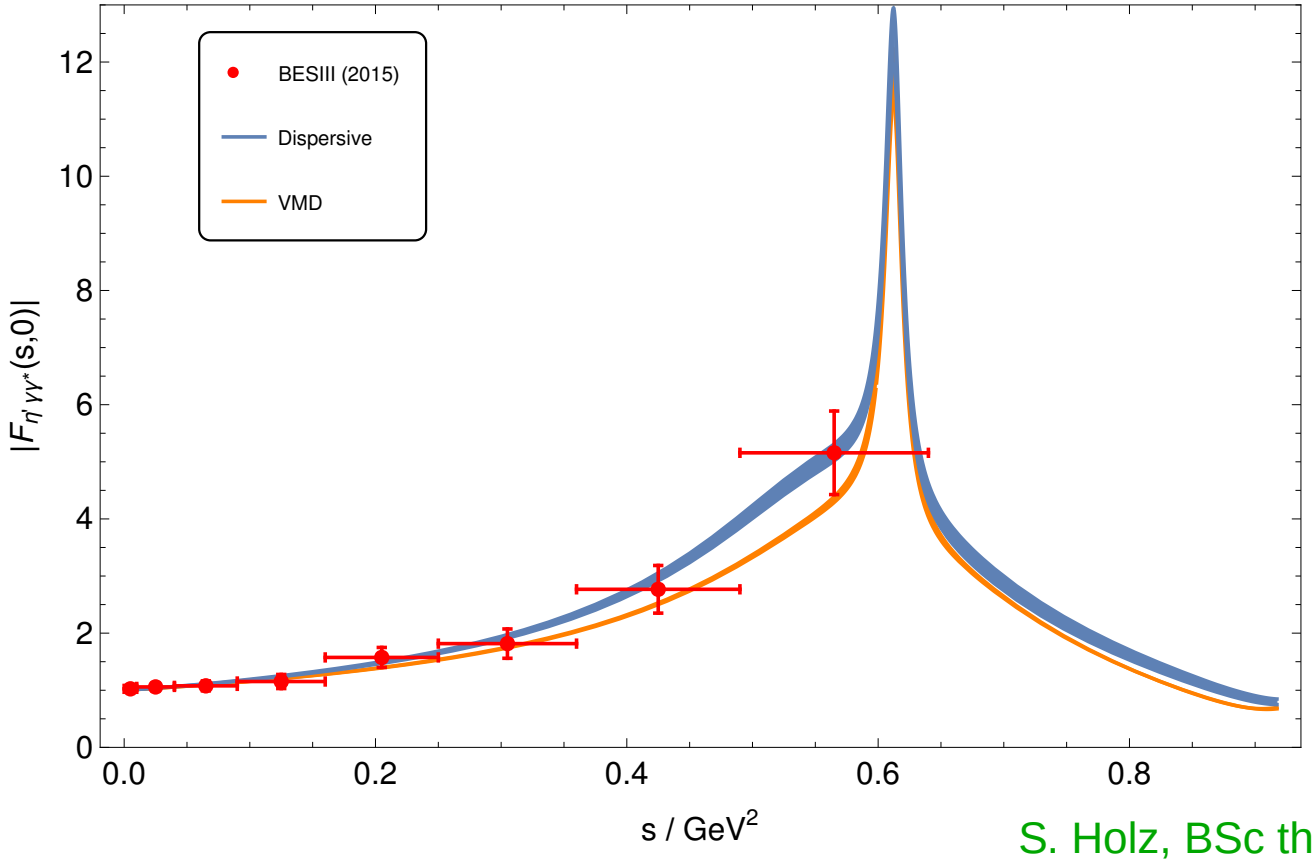
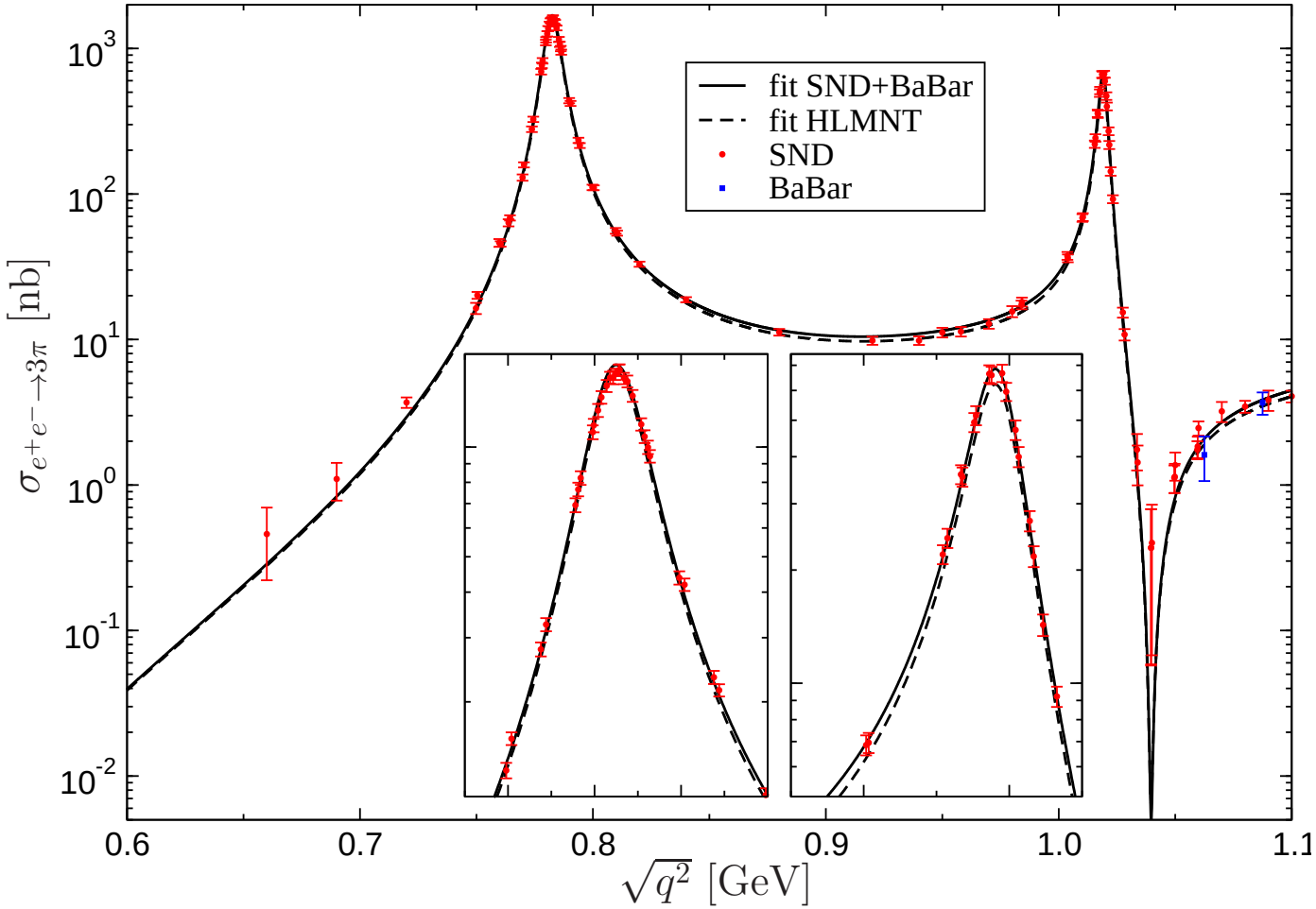




S. Holz, BSc thesis 2016

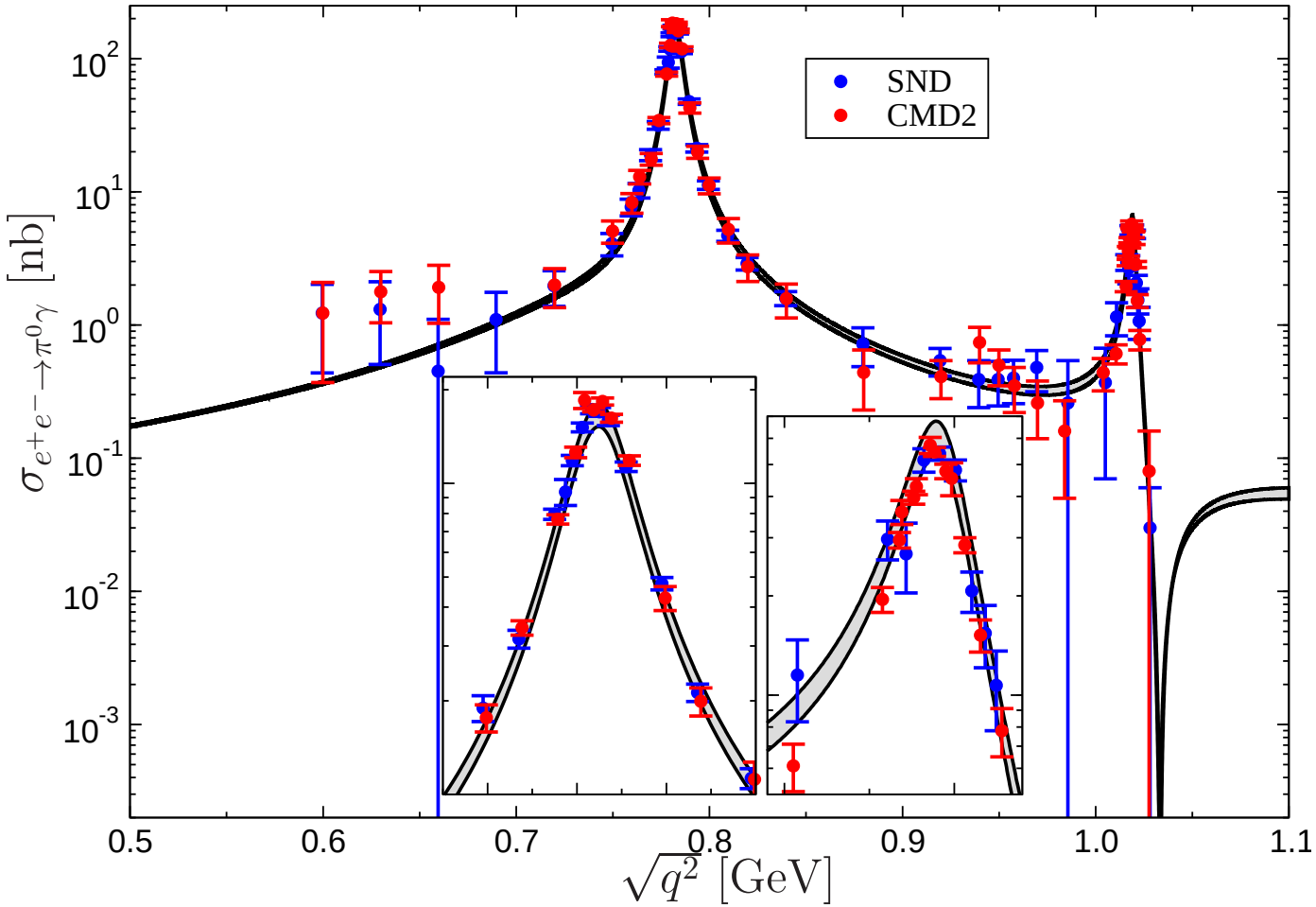
Fit parametrisation to $e^+e^- \to 3\pi$ data...



Hoferichter, Kubis, Leupold, Niecknig, Schneider 2014

- one subtraction/normalisation at $q^2 = 0$ fixed by $\gamma \to 3\pi$
- fitted: ω, ϕ residues, linear subtraction β

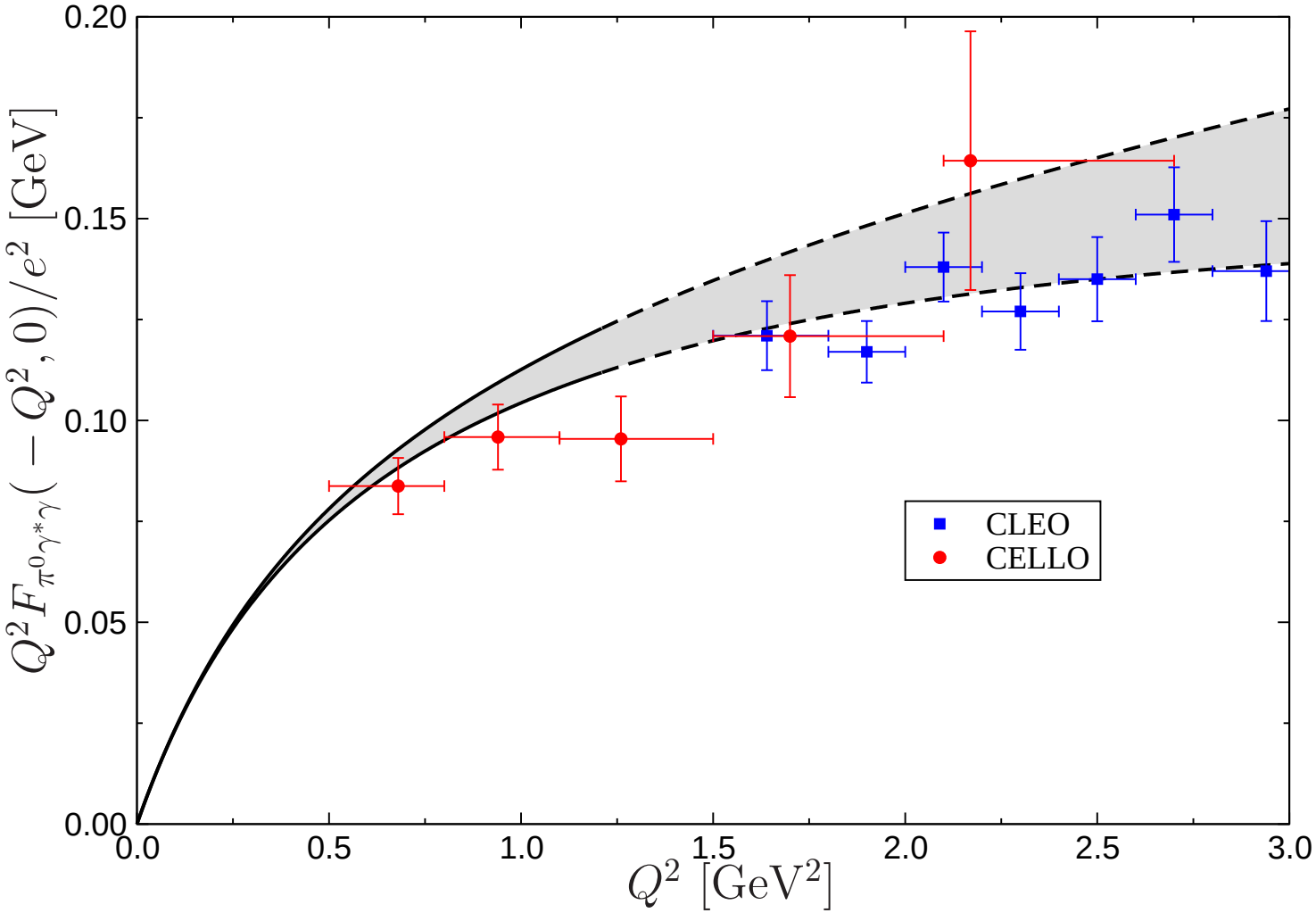
…predict/compare to $e^+e^- \to \pi^0\gamma$ data



Hoferichter, Kubis, Leupold, Niecknig, Schneider 2014

- "prediction"—no further parameters adjusted
- data very well reproduced

Prediction spacelike form factor



Hoferichter, Kubis, Leupold, Niecknig, Schneider 2014

$\longrightarrow$ more precise low-energy spacelike data to come BESIII

Work in progress: high-energy constraints

- (low-energy) double-spectral-function representation:

$$F_{\pi^0\gamma^*\gamma^*}(q_1^2,q_2^2) = \frac{1}{\pi^2}\int_{s_{\text{thr}}}^{s_{\text{m}}} \mathrm{d}x \int_{4M_\pi^2}^{s_{\text{m}}} \mathrm{d}y \left[\frac{\rho^{\text{disp}}(x,y)}{(x-q_1^2)(y-q_2^2)} + (q_1^2 \leftrightarrow q_2^2)\right]$$

- light-cone pQCD representation in terms of pion wave function:

$$F_{\pi^0\gamma^*\gamma^*}(q_1^2,q_2^2) = -\frac{2e^2F_\pi}{3}\int_0^1 \mathrm{d}x \frac{\phi_\pi(x)}{xq_1^2+(1-x)q_2^2}$$

$$\longrightarrow \frac{1}{\pi^2}\int_{s_{\text{m}}}^{\infty} \mathrm{d}x \int_{s_{\text{m}}}^{\infty} \mathrm{d}y \frac{\rho^{\text{pQCD}}(x,y)}{(x-q_1^2)(y-q_2^2)}$$

- the sum $\rho(x,y) = \rho^{\text{disp}}(x,y) + \rho^{\text{pQCD}}(x,y)$ should reproduce
  - ▷ Brodsky–Lepage limit $\lim_{Q^2\to\infty} F_{\pi^0\gamma^*\gamma}(-Q^2,0) = \frac{2\,e^2\,F_\pi}{Q^2}$
  - ▷ OPE limit $\lim_{Q^2\to\infty} F_{\pi^0\gamma^*\gamma^*}(-Q^2,-Q^2) = \frac{2\,e^2F_\pi}{3\,Q^2}$

Long Bai et al., in progress