Whys and Hows of Baryon Transition Form Factors

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EMMI RRTF meeting, GSI, October 2013

The Rapid Reaction Task Force

Transition form factors (TFFs) — why?

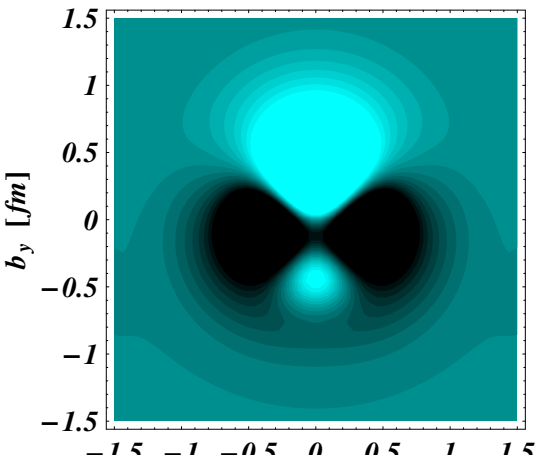
- amplitude for reaction $A \to B\ e^+e^-$ (or $A\ e^- \to B\ e^-$) can be decomposed:

$$\mathcal{M} = F_{AB} \cdot \mathcal{M}_{A,B\ \text{pointlike}}$$

with form factor F_{AB}

↪ F_{AB} tells about intrinsic structure

- in general: electromagnetic probes are a good tool to look inside of strongly interacting "matter" (single hadron, hadronic matter, quark-gluon plasma, . . .)



p-$N^*(1520)$ (polarized)

Tiator et al., Eur. Phys. J. ST 198 (2011) 141

TFFs — kinematically accessible regions

q^2: invariant mass of virtual photon
s: (square of) reaction energy in cms
R: baryon resonance with mass M_R

- $e^- N \to e^- R$:

$$-\frac{1}{s}\left(s^2 + M_N^2\, M_R^2 - s\, M_N^2 - s\, M_N^2\right) < q^2 < 0$$

- $R \leftrightarrow N\gamma$: $q^2 = 0$
- $R \to N\, e^+ e^-$: $0 < q^2 < (M_R - M_N)^2$
- $e^+ e^- \to R\bar{N}$ $(\bar{R}N)$: $s = q^2 > (M_R + M_N)^2$

- i.e. dilepton production kinematically close to space-like region!

$\hookrightarrow$ similar physics(?)

TFFs — how? $\rightsquigarrow$ general remarks:

- $2 \to 2$ reactions and three-body decays have two free kinematic variables (e.g. Mandelstam's s, t)

$\hookrightarrow$ Dalitz plots, partial-wave analysis ($t \to l$), ...

$\hookrightarrow$ scattering/decay amplitudes are analytic functions (in s) except for cuts $\hat{=}$ inelasticities

$\hookrightarrow$ iff all inelasticities are known one can reconstruct amplitude dispersively up to subtraction constant(s)

$$\mathcal{M}_l(s) = \mathcal{M}_l(0) + \frac{s}{\pi} \int_{-\infty}^{\infty} ds' \, \frac{\mathrm{Im}\mathcal{M}_l(s')}{s' \, (s' - s - i\epsilon)}$$

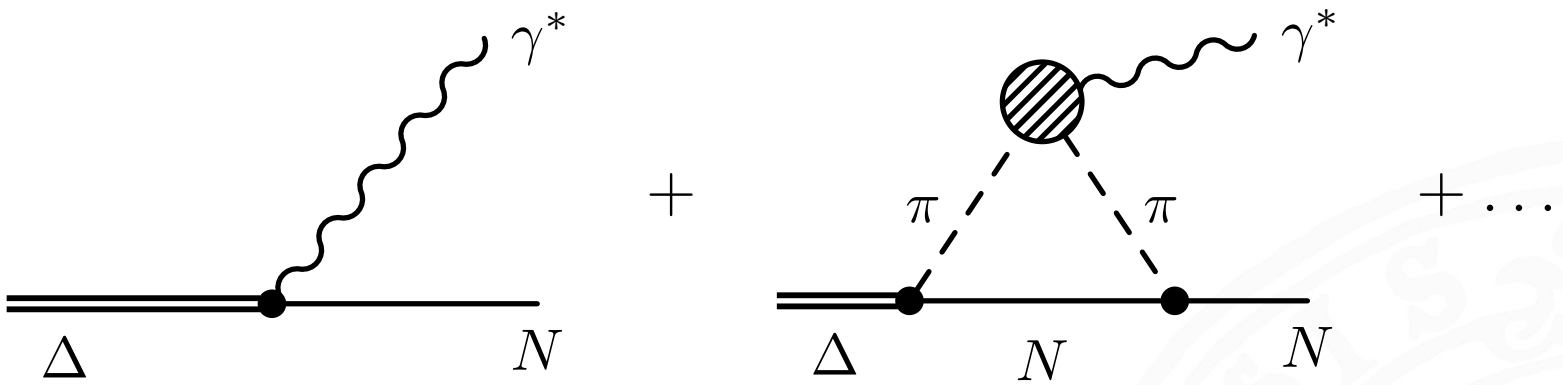
$\hookrightarrow$ obtain inelasticities from hadron theory or data

$\hookrightarrow$ subtraction constant(s) from matching to perturbative QCD or lattice or Dyson-Schwinger or quark model ...

Example: TFF of a Δ resonance

- consider $\Delta \to N\, e^+ e^-$ (or $N\, e^- \to \Delta\, e^-$)

$\hookrightarrow$ presumably πN loop is important

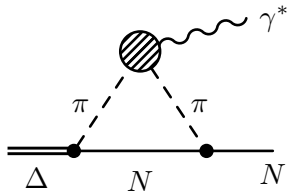


$\hookrightarrow$ study cuts ($\hat{=}$ inelasticities) of loop diagram(s) $\rightsquigarrow$ next slide

- note: first diagram is essentially pure number,
  related to subtraction constants and to real photon

$\hookrightarrow$ everything settled for real photon, i.e. $\Delta \to N\, \gamma$?

Example: TFF of a Δ resonance

cuts of 

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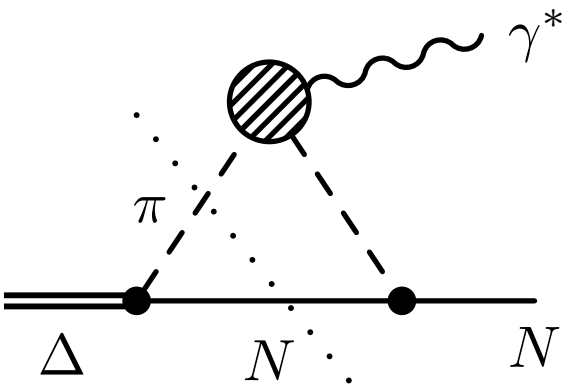
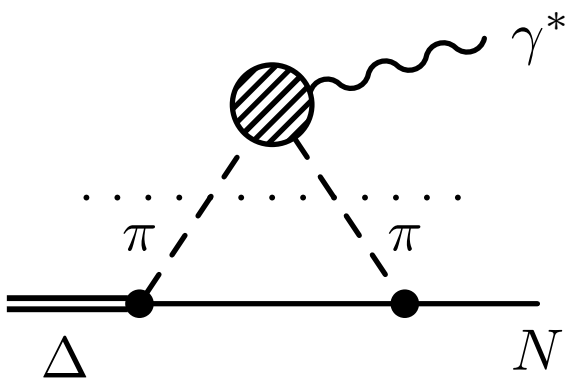
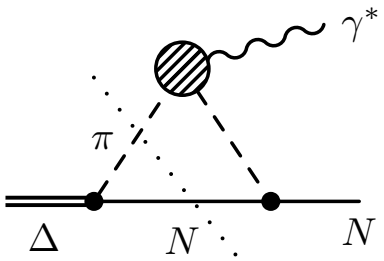


$\Delta \to \pi N, \quad \pi N \to \gamma^* N$

the pion cloud: 

$\Delta \to \pi\pi N, \quad \pi\pi \to \gamma^*$

Where to get the information from?



- $\Delta \to \pi N$: clear, just a number

$\hookrightarrow$ from data or microscopic approaches
(quark models, Dyson-Schwinger, lattice-QCD, ...)

- $\pi N \leftrightarrow \gamma^* N$:

$\hookrightarrow$ time-like: HADES pion beam

$\hookrightarrow$ space-like $\hat{=}$ electroproduction of pions (MAMI, JLAB)

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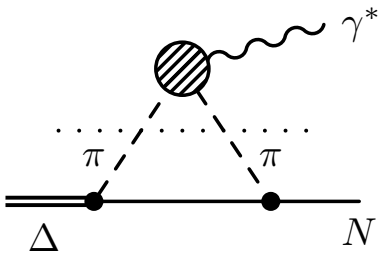

(pion cloud)

- $\Delta \to \pi\,\pi\,N$:

↪ e.g. from data on $\pi\,N \to \Delta \to \pi\,\pi\,N$

↪ HADES pion beam can improve data basis

- $\pi\,\pi \to \gamma^*$:

↪ pion form factor, very well known

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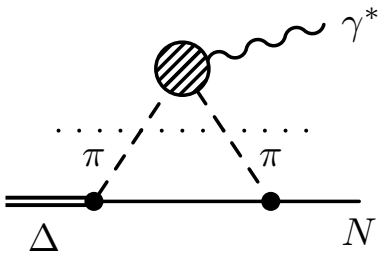

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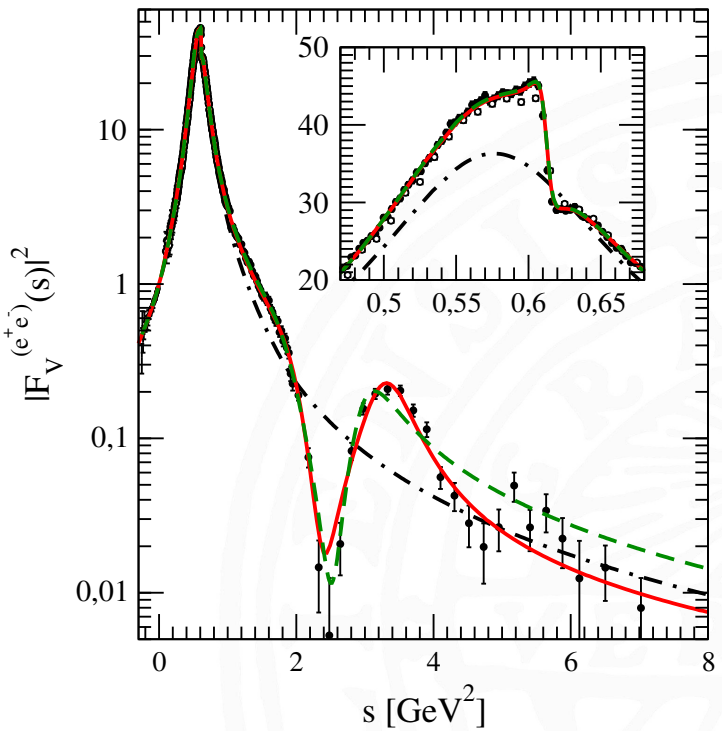


Hanhart, Phys.Lett. B715 (2012) 170

Some open questions

- what can we learn about time-like region, $\pi N \to N e^+ e^-$, from space-like data, $e^- N \to e^- \pi N$ (MAMI, JLAB)?

- challenging: partial-wave analysis of $\pi N \to \Delta \to \pi \pi N$

$\hookrightarrow$ model dependence/independence?

- everything settled for real photon, i.e. $\Delta \to N \gamma$?

$\hookrightarrow$ contradicting basic formulae in literature?
(see Krivoruchenko/Fässler, Phys.Rev. D65 (2002) 017502)

- if hadronic and microscopic models are fused: double counting?

$\hookrightarrow$ ρ-meson appears in pion form factor

$\hookrightarrow$ part of pion cloud

Some open questions, cont.

specific models:

1. prediction for $\pi N \to N e^+ e^-$ from Rapp/Wambach model? (should be possible, $\gamma N \to X$ already done)

2. naive translation of a model for space-like region (Iacello) to time-like region seems to create ρ bump at wrong position
   $\hookrightarrow$ on the other hand: accessible invariant masses of dilepton:

$$m_{e^+e^-} \leq m_\Delta - m_N \approx (1232 - 940)\,\mathrm{MeV} \ll m_\rho$$

   $\hookrightarrow$ Is it meaningful to talk about an offshell Δ and its transition form factor?

Some open questions, cont.

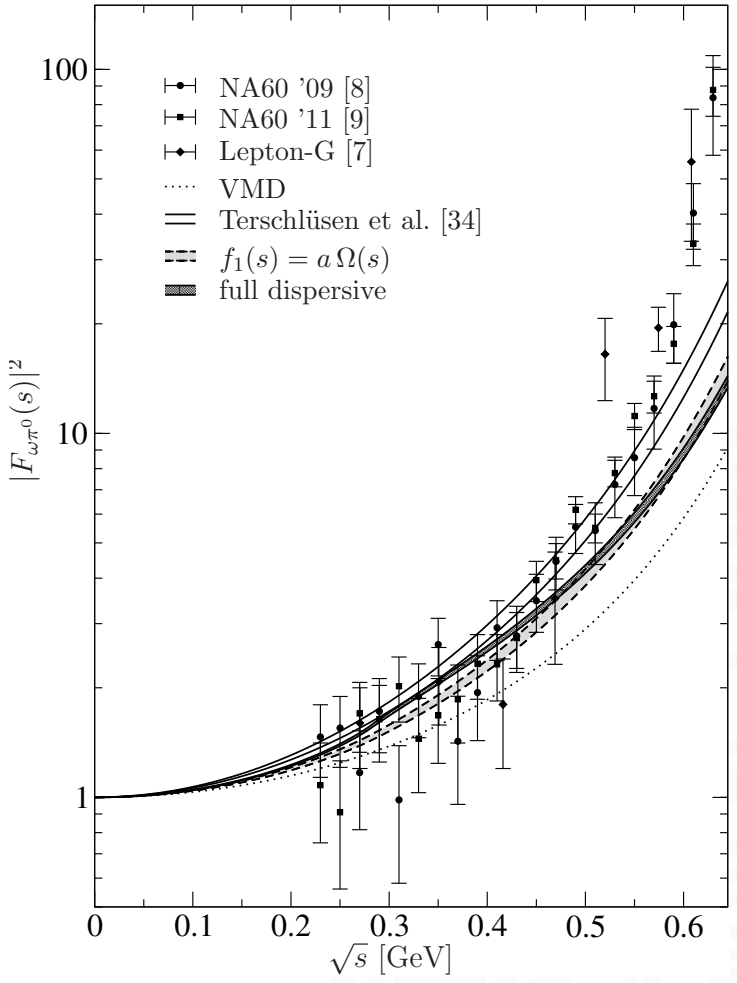
connection to in-medium physics:

- which baryon resonances are important for dilepton production in vector-meson region?
  $\Delta(1232)$? $N^*(1520)$? ...
- how to pin down their properties?

Meson TFFs and VMD

How good is vector meson dominance (VMD)?

$\omega \to \pi\, e^+ e^-$



Schneider, Kubis, Niecknig,

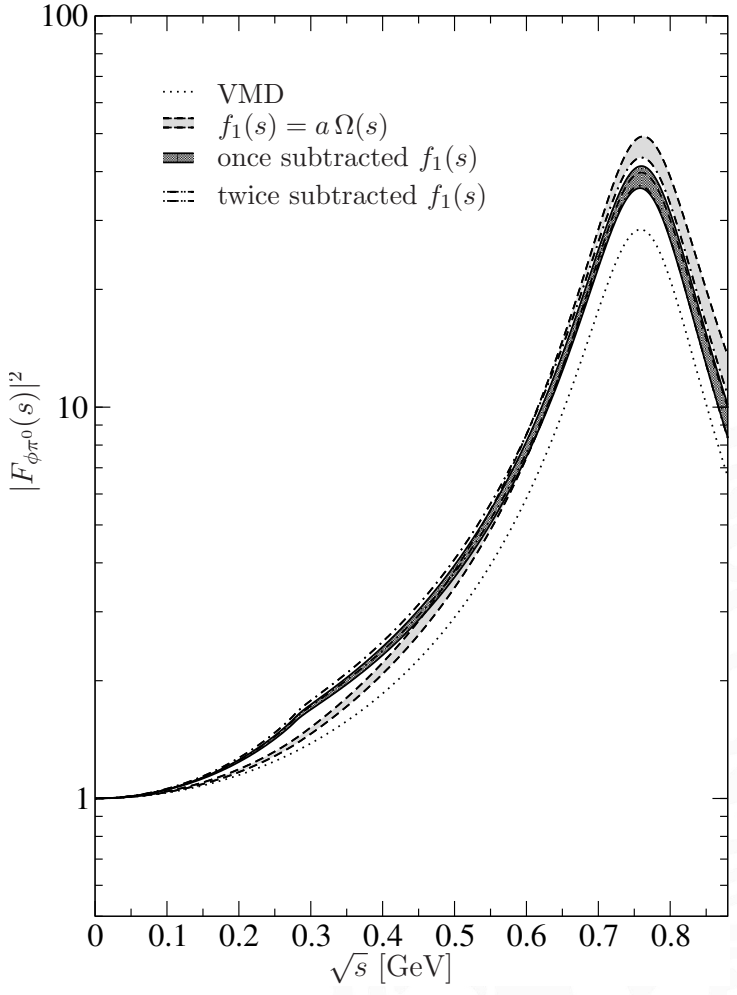
Phys.Rev. D86 (2012) 054013

How good is VMD?

$\phi \to \pi\, e^+ e^-$

dispersive calculation $\to$

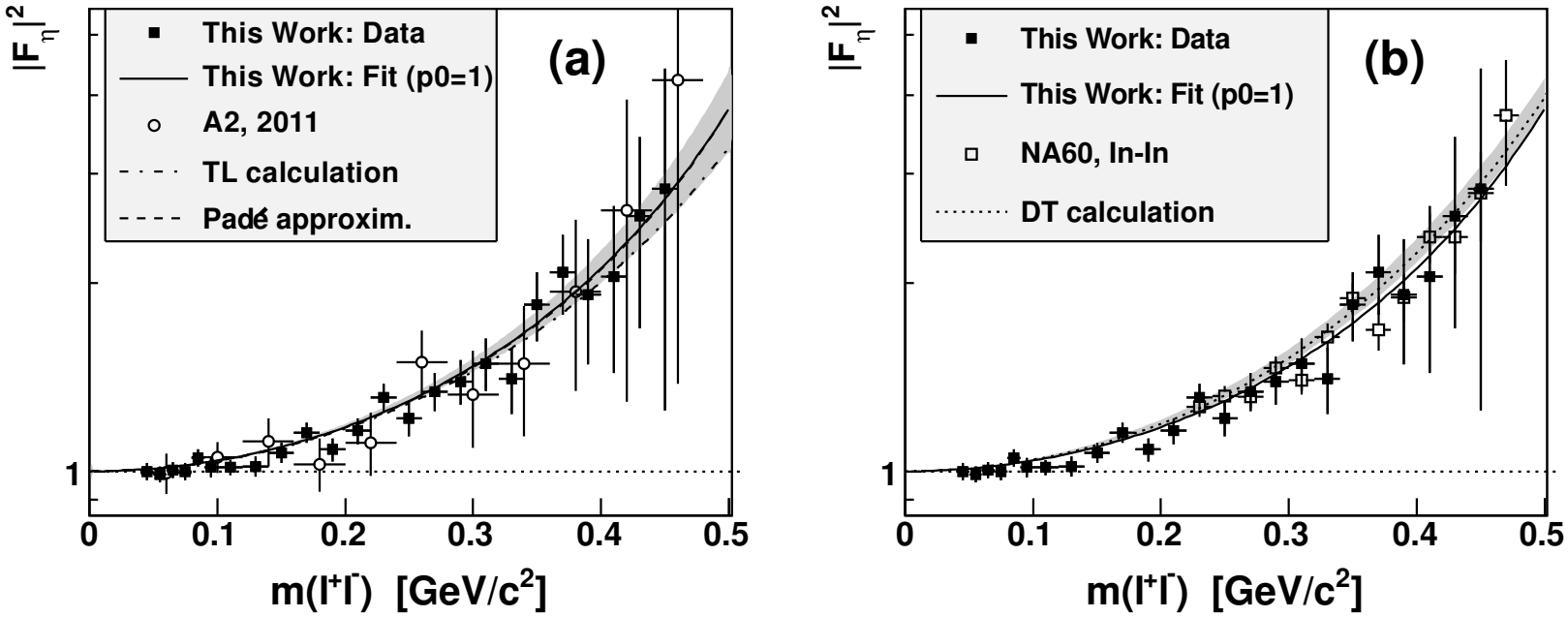
$\hookrightarrow$ data from KLOE(?)



Schneider, Kubis, Niecknig,

Phys.Rev. D86 (2012) 054013

$\eta \to \gamma e^+ e^-$



A2 collaboration, arXiv:1309.5648 [hep-ex]

DT: Hanhart, Kupsc, Meissner, Stollenwerk, Wirzba, arXiv:1307.5654 [hep-ph],

TL: essentially VMD