Calculating transitions on the lattice
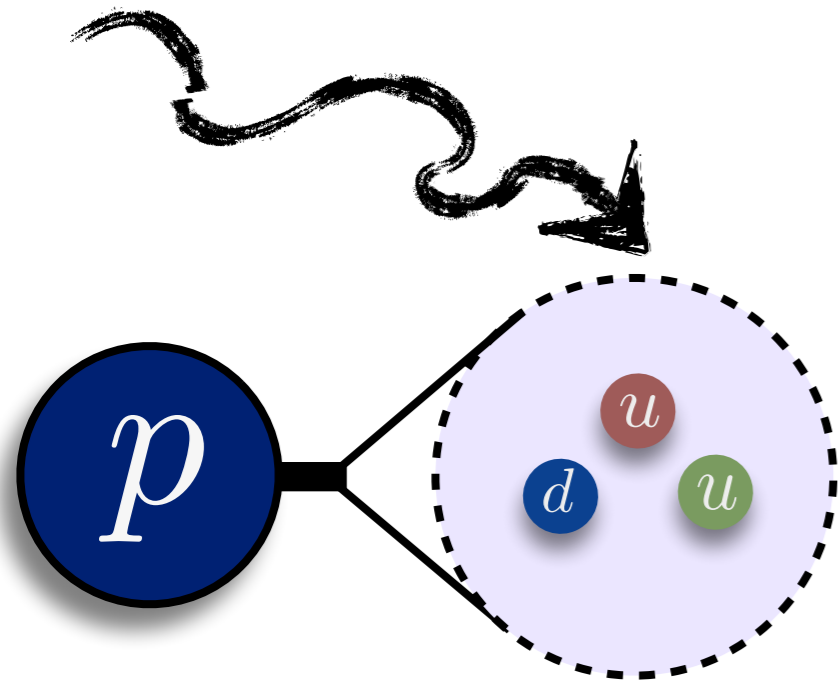
Raúl Briceño

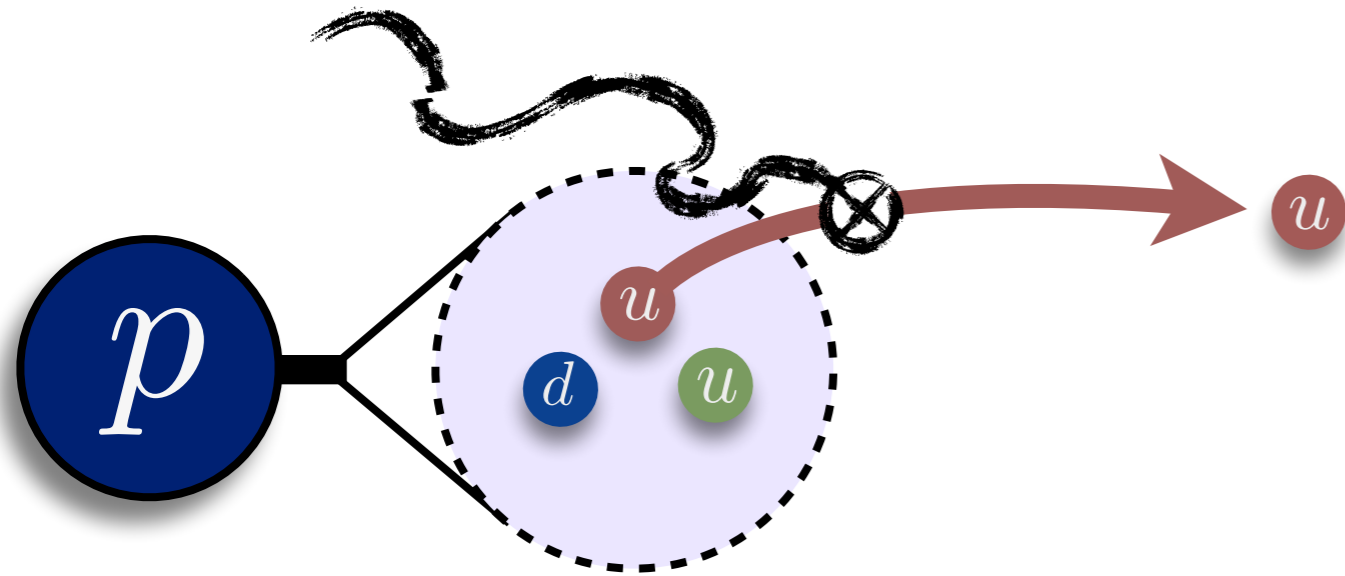rbriceno@jlab.org

Jefferson Lab

S&T Review July, 2015

Transition processes
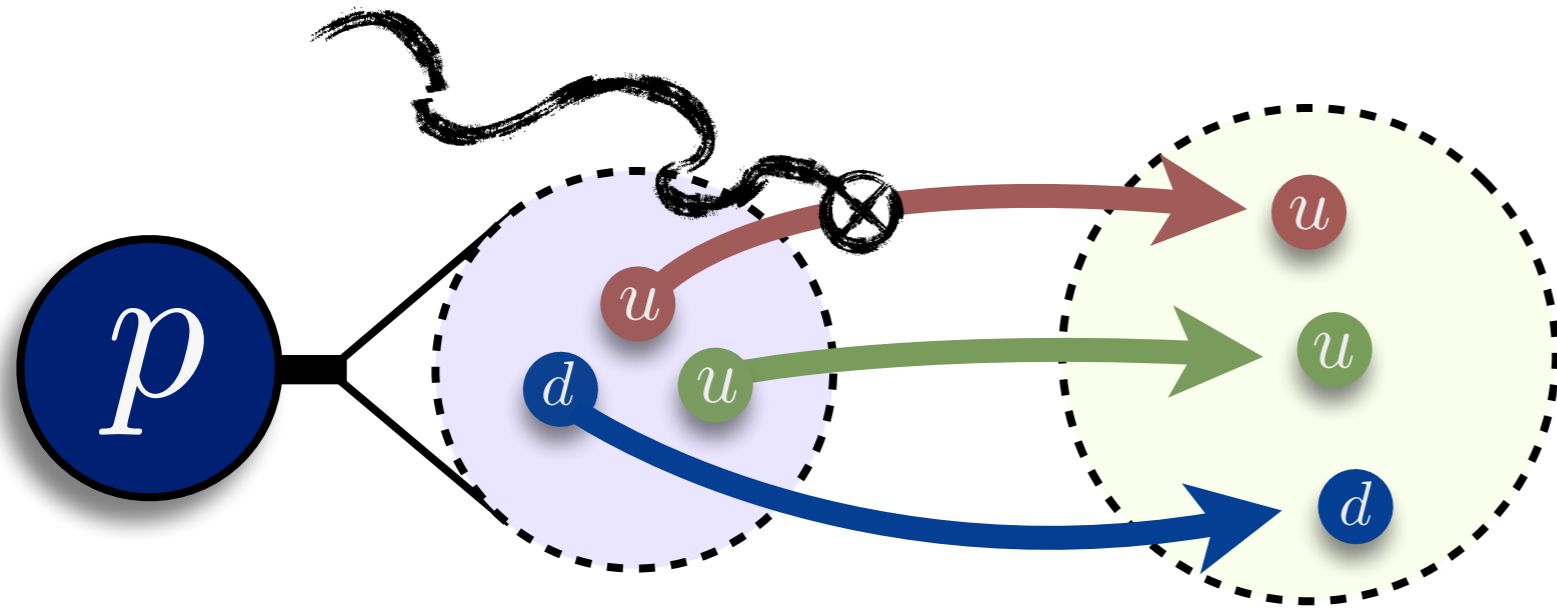## (e.g., meson photo/electro-production)

Transition processes
(e.g., meson photo/electro-production)

Transition processes
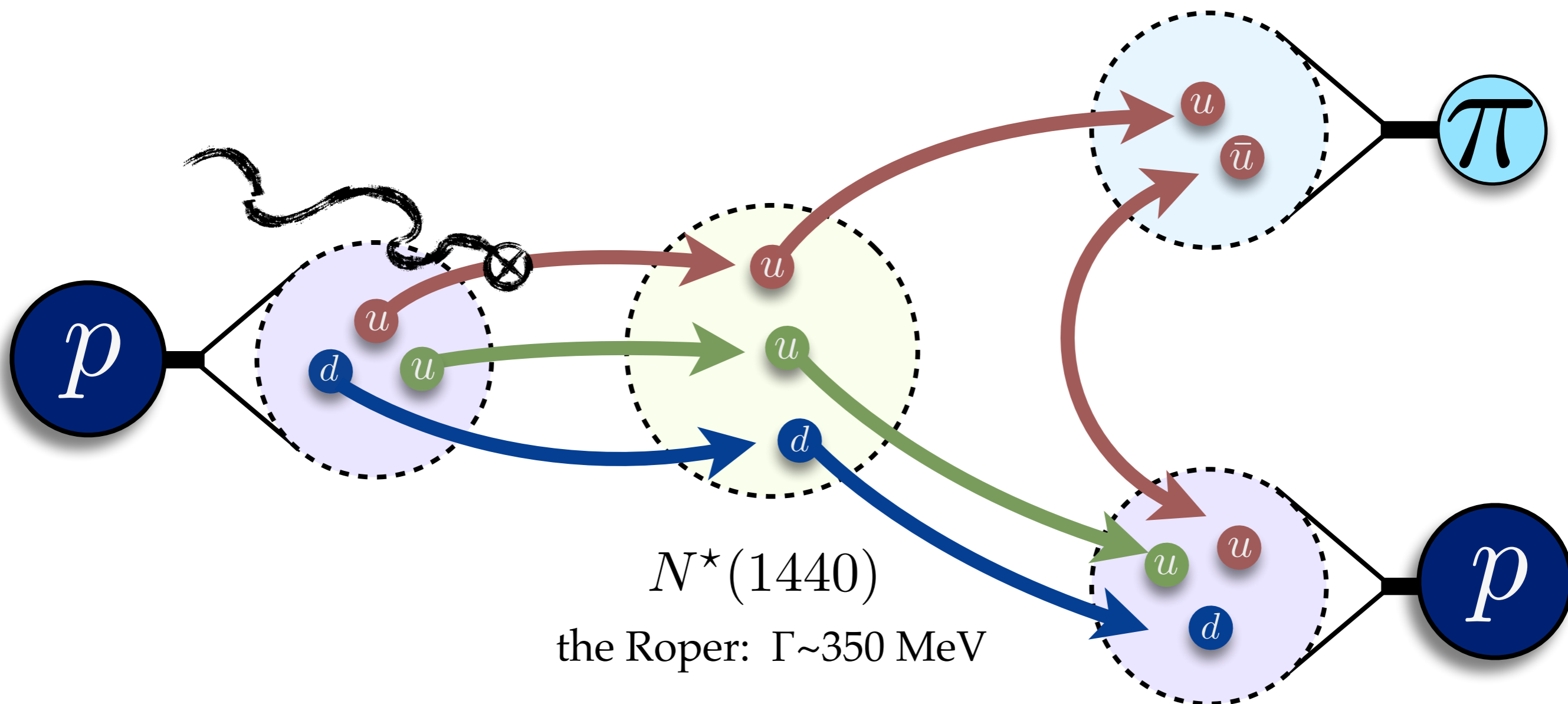## (e.g., meson photo/electro-production)

$N^{\star}(1440)$

the Roper: $\Gamma \sim 350$ MeV

Transition processes
(e.g., meson photo/electro-production)

$N^\star(1440)$
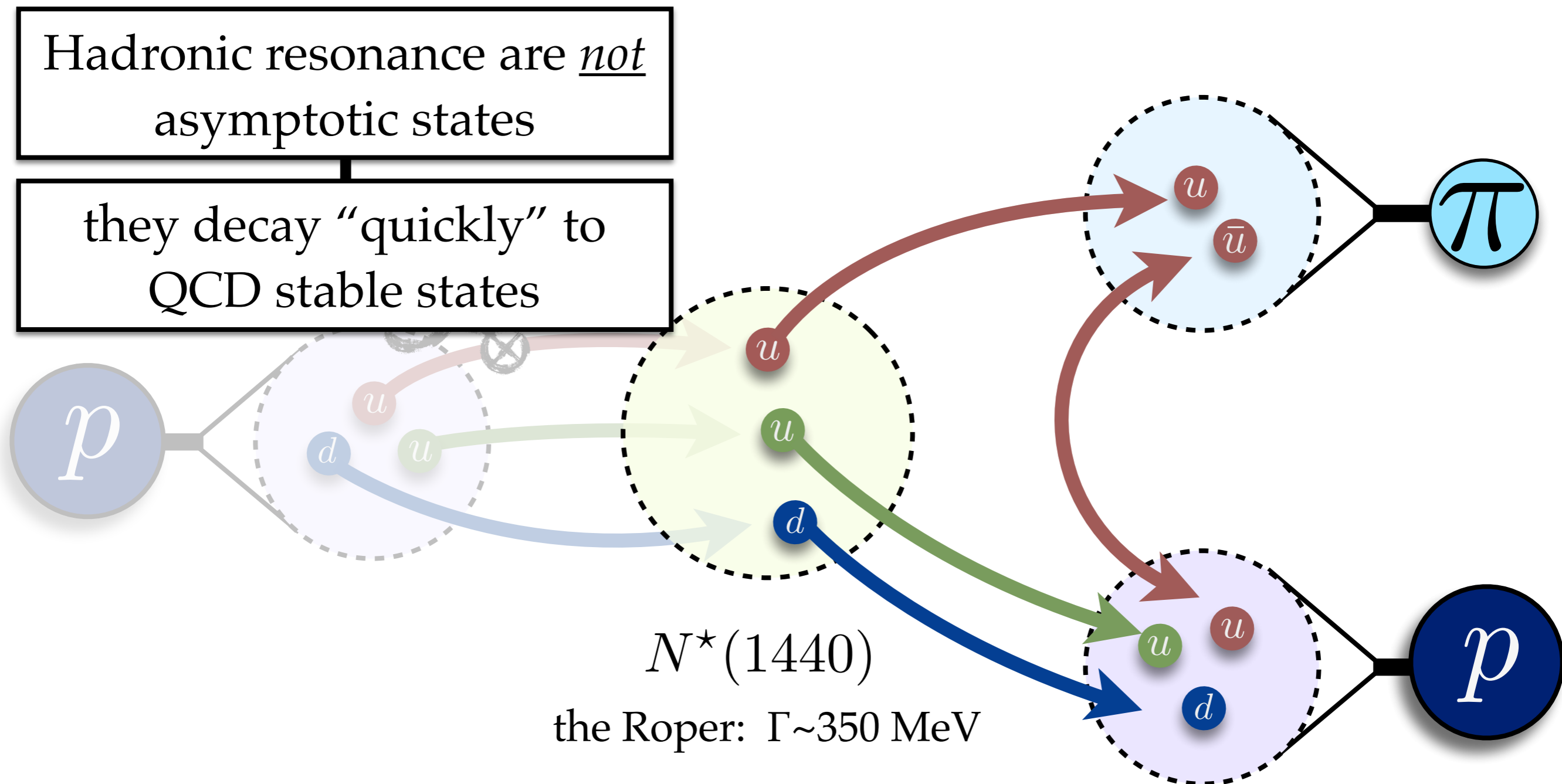
the Roper: $\Gamma \sim 350$ MeV

Transition processes
(e.g., meson photo/electro-production)

Hadronic resonance are *not* asymptotic states

they decay "quickly" to QCD stable states

$N^\star(1440)$

the Roper: $\Gamma \sim 350$ MeV

Transition processes
(e.g., meson photo/electro-production)

Lattice QCD, the only available theoretical tool that:

📌 Is non-perturbative in QCD

📌 Generates resonating states dynamically

📌 Allows resonances to decay in accordance to QCD

📌 Treats QED effects perturbatively (or non-perturbatively)

📌 ...

the Roper: $\Gamma \sim 350$ MeV

Seemingly impossible

Finite volume - a necessity for lattice QCD

- No asymptotic states, i.e., no scattering, resonances, etc.

- Challenging, but *not* an limitation

- Finite volume effects allow us to determine the S-matrix
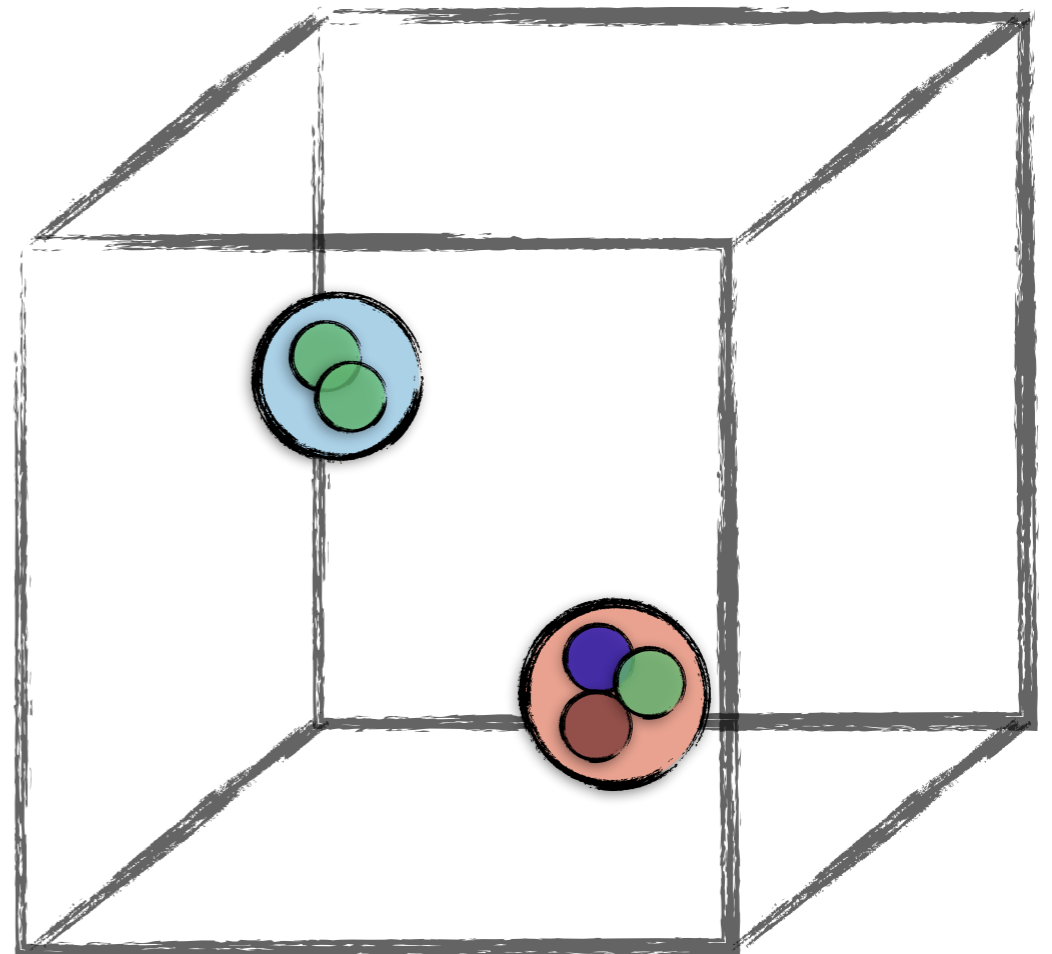
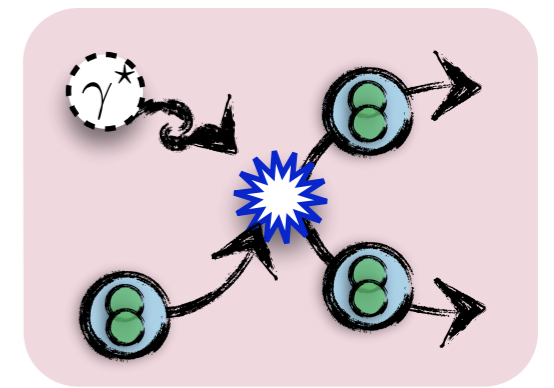## Proof for radiative processes:

Hansen
(Mainz)

Walker-Loud
(JLab/W&M)

RB, Hansen & Walker-Loud (2014)

RB & Hansen (2015)

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

- Exploratory $\pi\gamma^*$-to-$\pi\pi$ / $\pi\gamma^*$-to-ϱ calculation

- proof of principle/demonstration

- $m_\pi \sim 400\text{MeV}$

- Over **500 matrix elements** are measured:

  corresponding to **48** different kinematic point
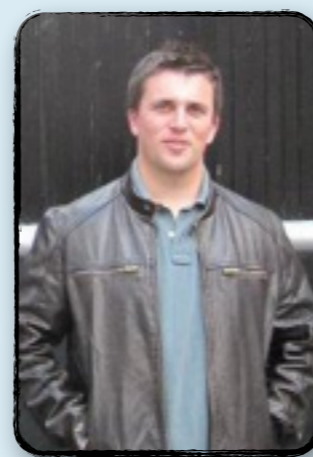
HadSpec Collaboration

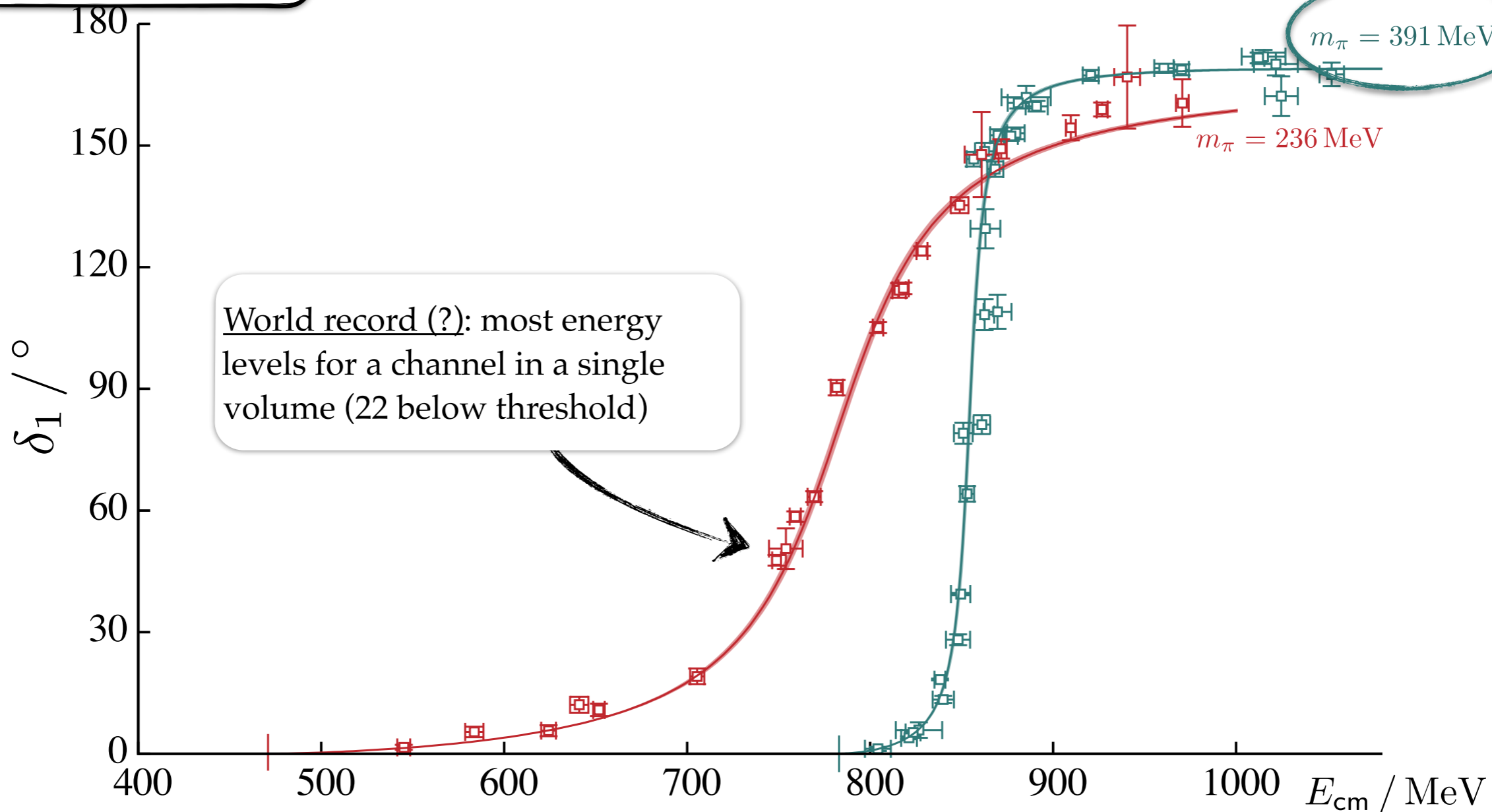| Dudek | Edwards | Shultz | Thomas | Wilson |

Elastic $\pi\pi$ scattering

(spectrum and interpretation)

HadSpec Collaboration

Thursday July 9, arXiv:1507.02599

$m_\pi = 391$ MeV

$m_\pi = 236$ MeV

World record (?): most energy levels for a channel in a single volume (22 below threshold)
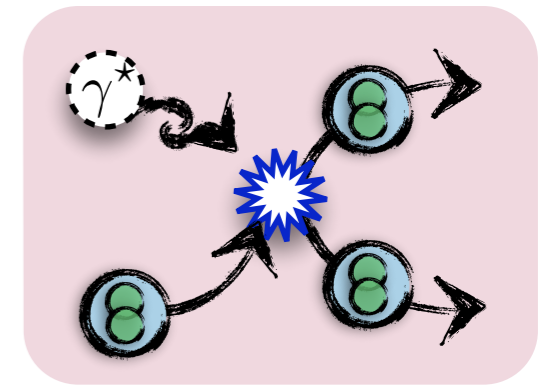
δ_1 / °

E_{cm} / MeV

$\pi\pi$ in I=1 channel

Dudek, Edwards & Thomas (2012)
Wilson, Briceño, Dudek, Edwards & Thomas (2015)

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

(a sketch)

On the lattice we calculate: $\quad _L\langle \pi; P_\pi | \mathcal{J}^\mu_{x=0} | \pi\pi; P_{\pi\pi}\rangle_L$

This can be *mapped* to : $\quad \langle \text{out}; \pi, P_\pi | \mathcal{J}^\mu_{x=0} | \text{in}; \pi\pi, P_{\pi\pi}, \ell = 1 \rangle$

RB, Hansen & Walker-Loud (2014)
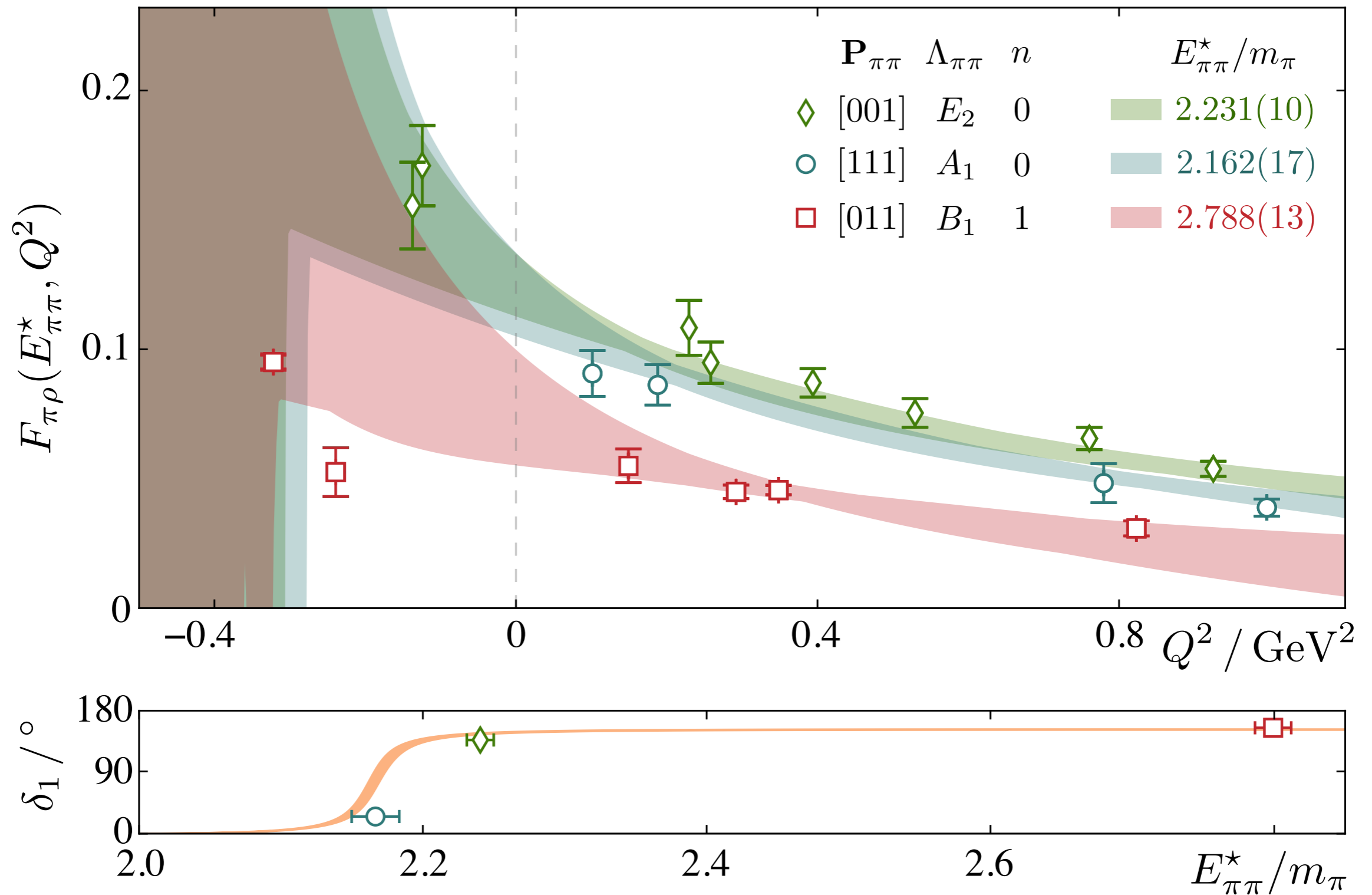
RB & Hansen (2015)

This gives us:

- energy-dependent π-to-ϱ form factor
- $\pi\gamma^*$-to-$\pi\pi$ amplitude for arbitrary virtuality
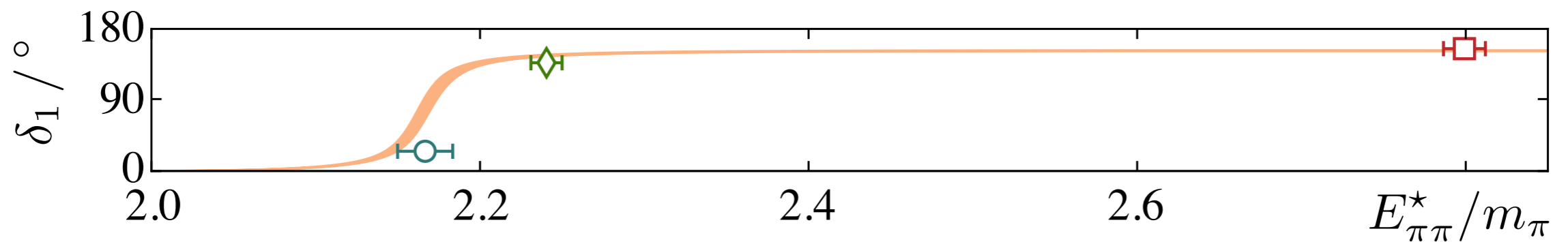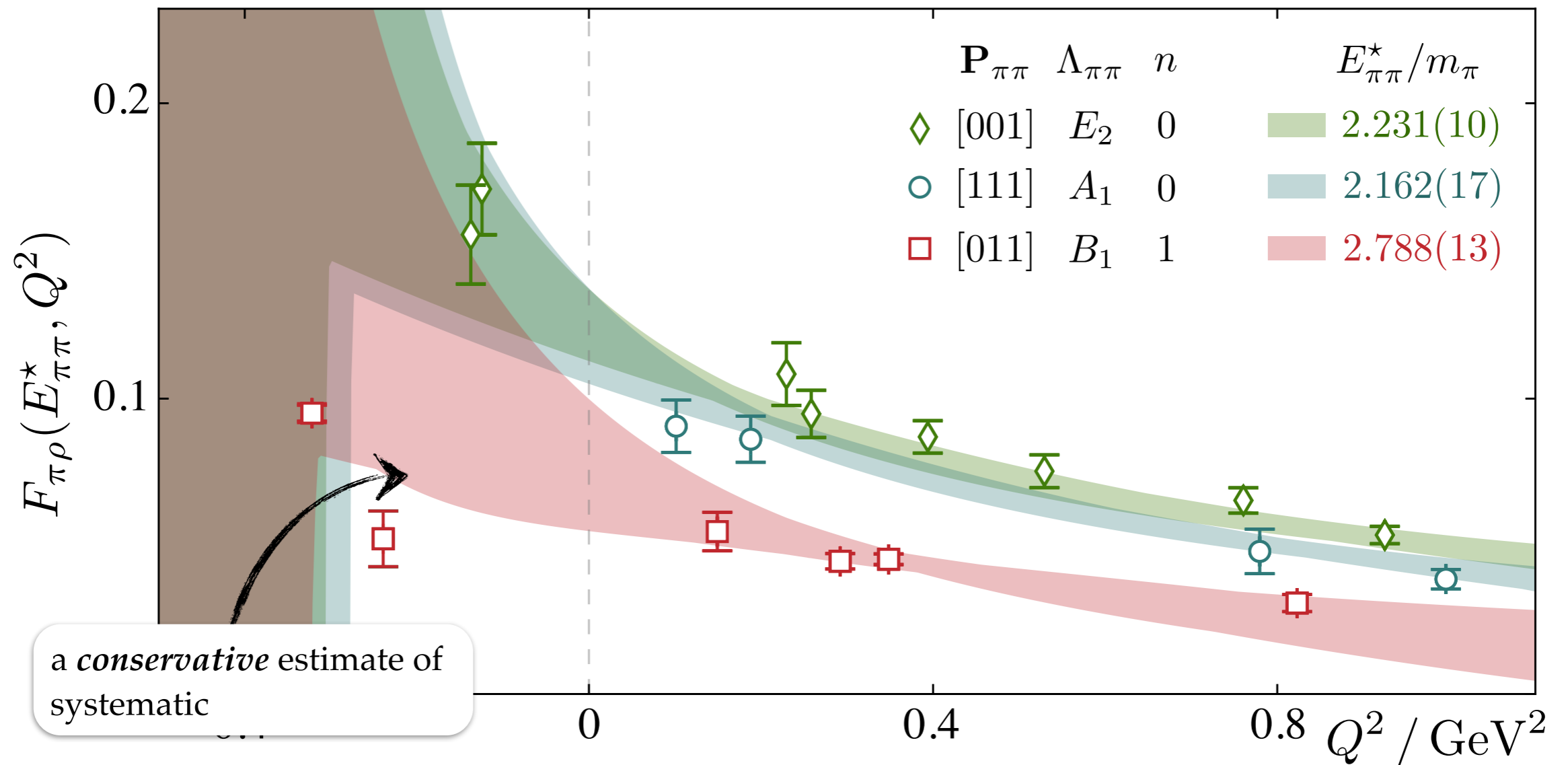- $\pi\gamma^*$-to-$\pi\pi$ cross section
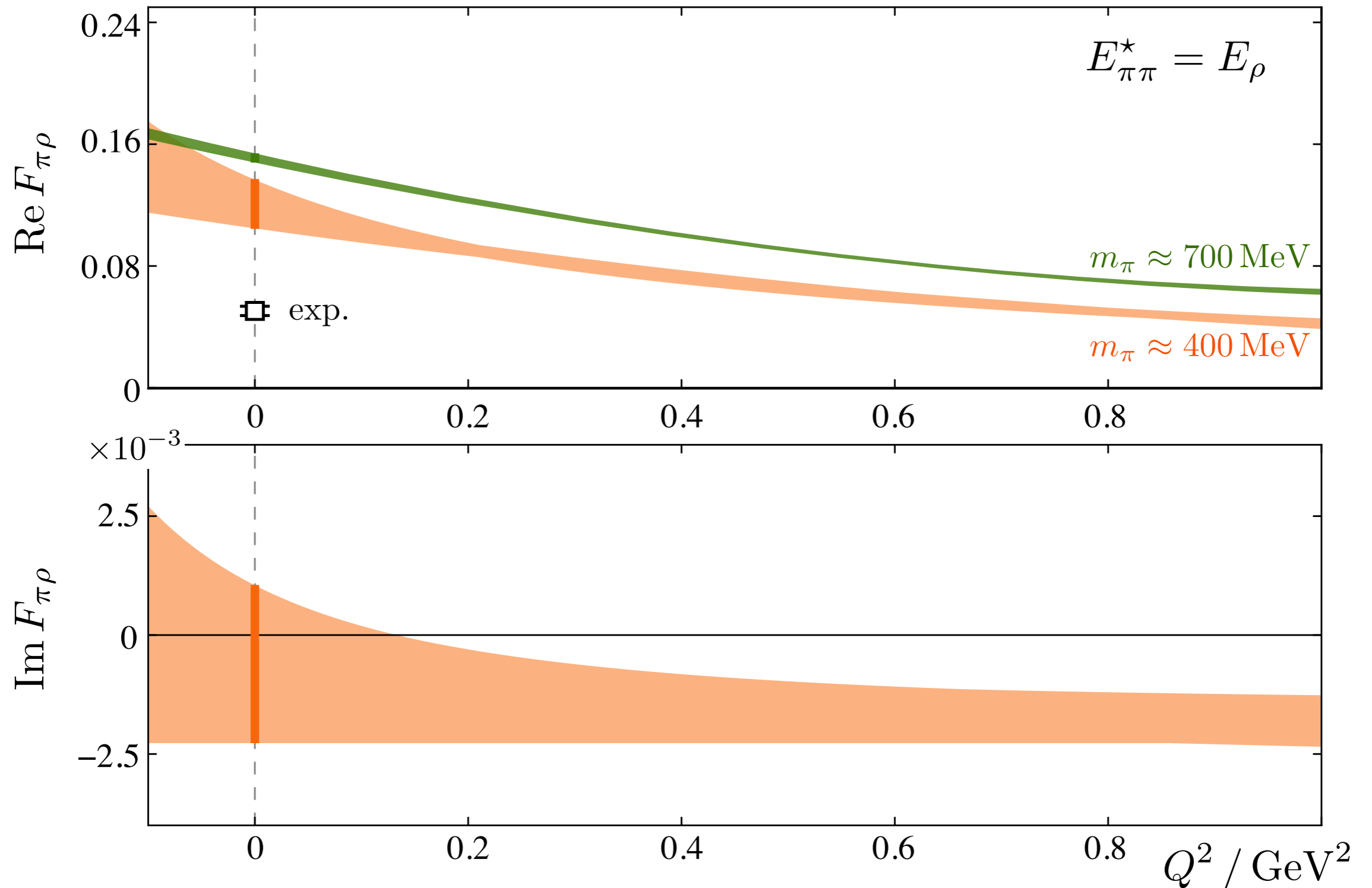
} <u>not independent</u>

Form factor

Form factor
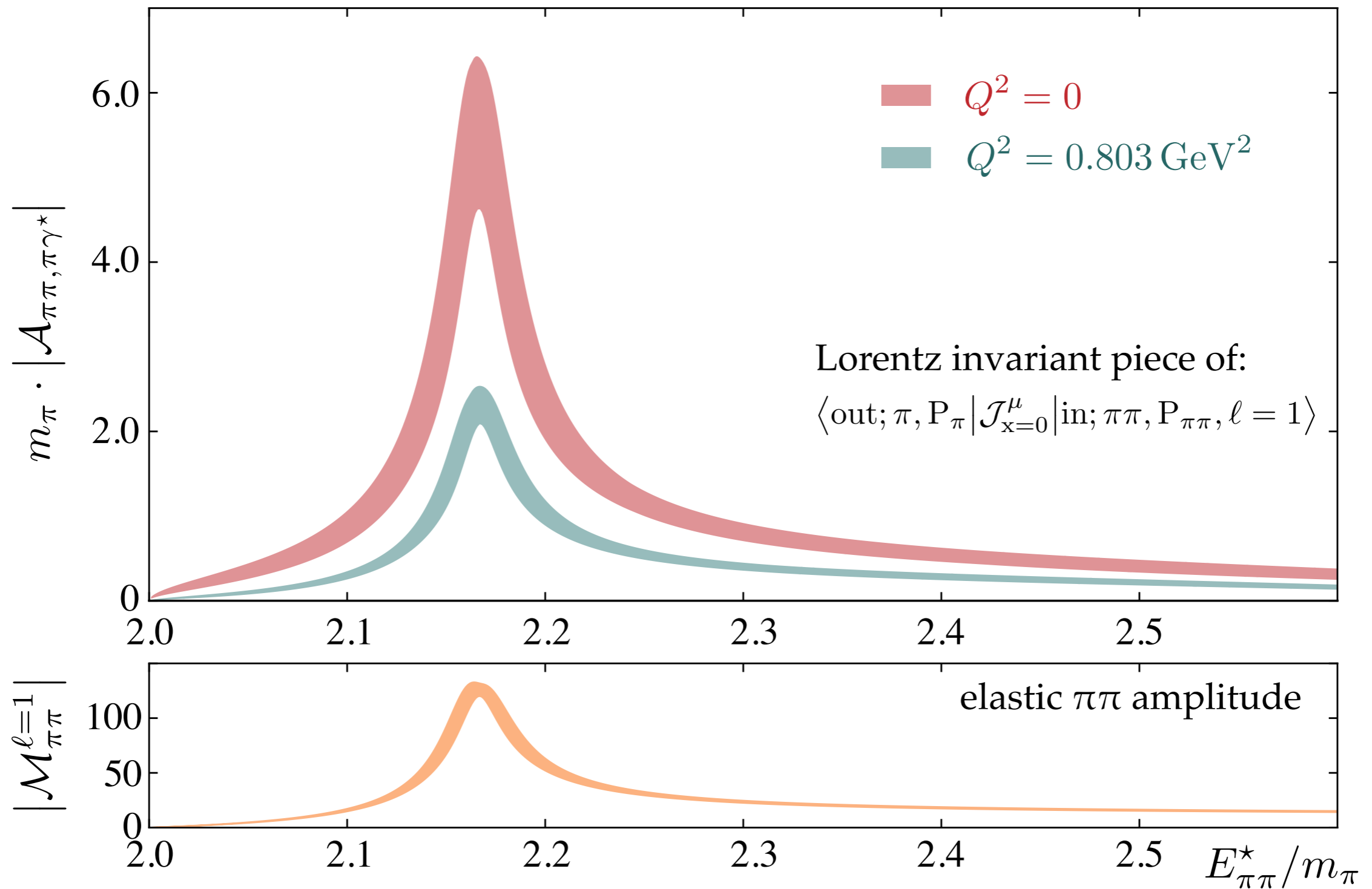
Form factor at ϱ pole
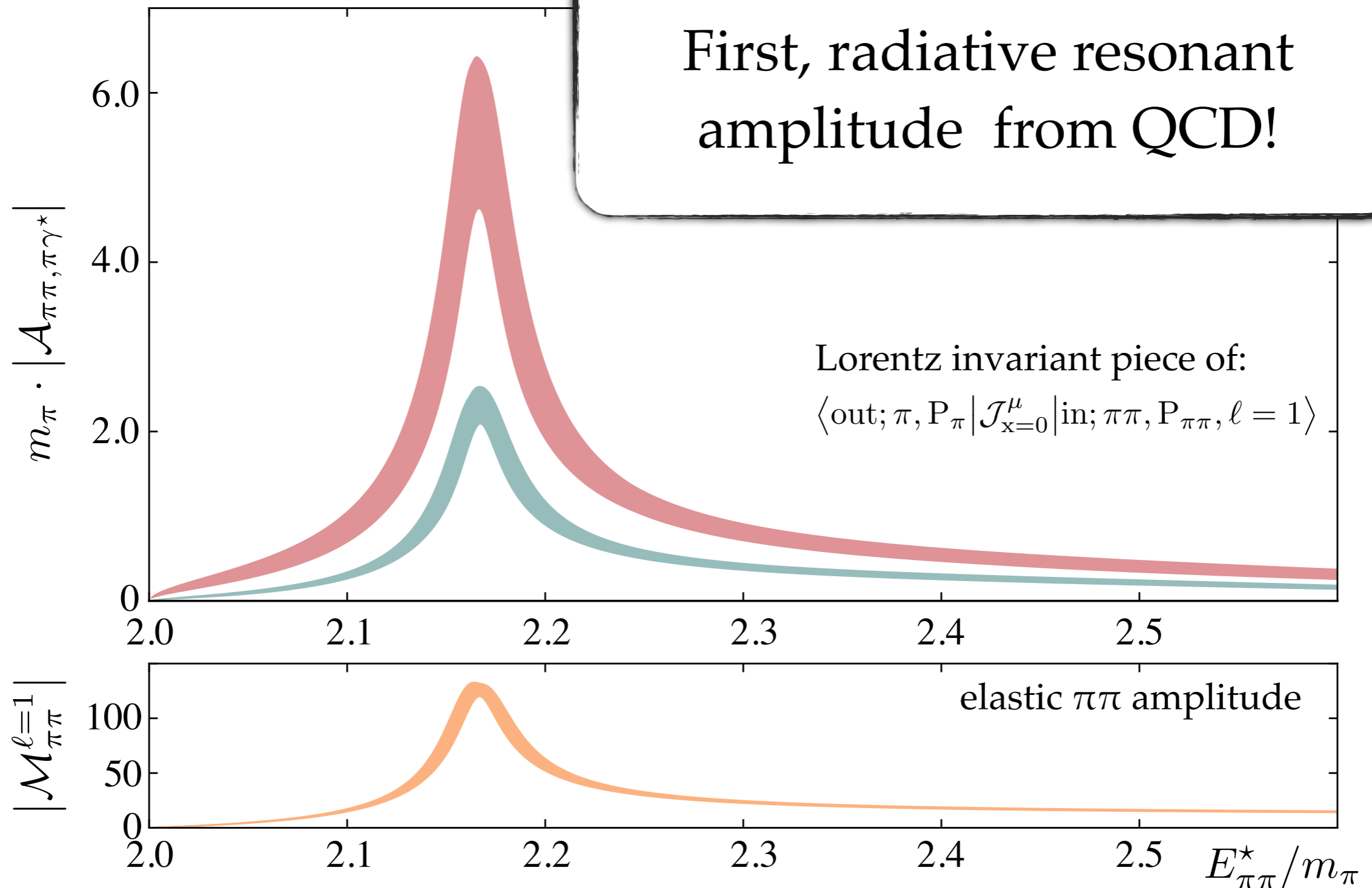
$\pi\gamma^*$-to-$\pi\pi$ amplitude

$\pi\gamma^*$-to-$\pi\pi$ amplitude

First, radiative resonant amplitude from QCD!

Lorentz invariant piece of:
$\langle \mathrm{out}; \pi, \mathrm{P}_\pi | \mathcal{J}^\mu_{\mathrm{x}=0} | \mathrm{in}; \pi\pi, \mathrm{P}_{\pi\pi}, \ell = 1 \rangle$

elastic $\pi\pi$ amplitude

$\pi\gamma^*$-to-$\pi\pi$ cross section

The Future!

(on-going *formal* efforts)

Elastic form factor of resonance:
(e.g., Nπ-to-Nπγ*)

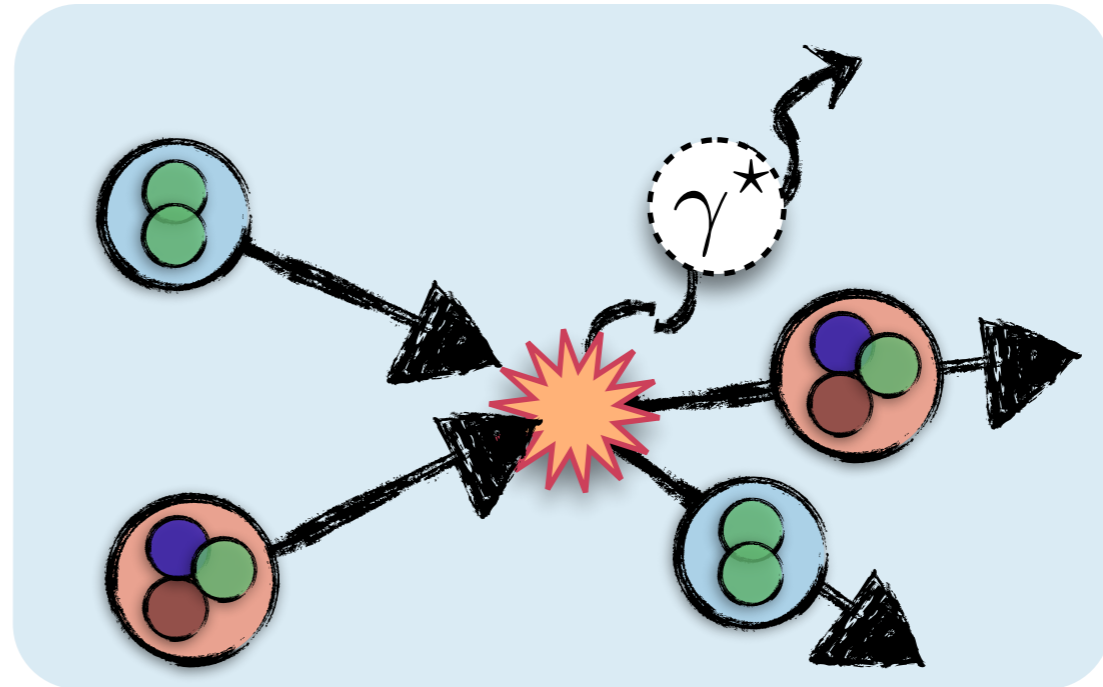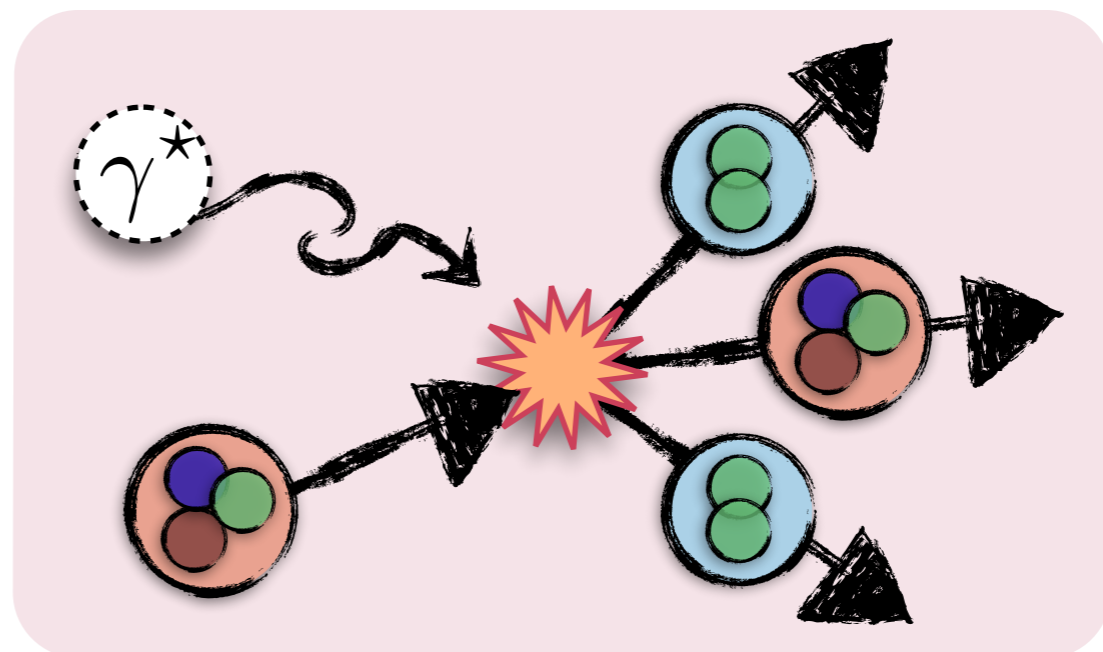Photo-production of two mesons:
(e.g., Nγ*-to-Nππ)

WORK IN PROGRESS

Hansen
(Mainz)