

Understanding exotic mesons

Arkaitz Rodas

REACHING FOR THE HORIZON



The Site of the Wright Brothers' First Airplane Flight

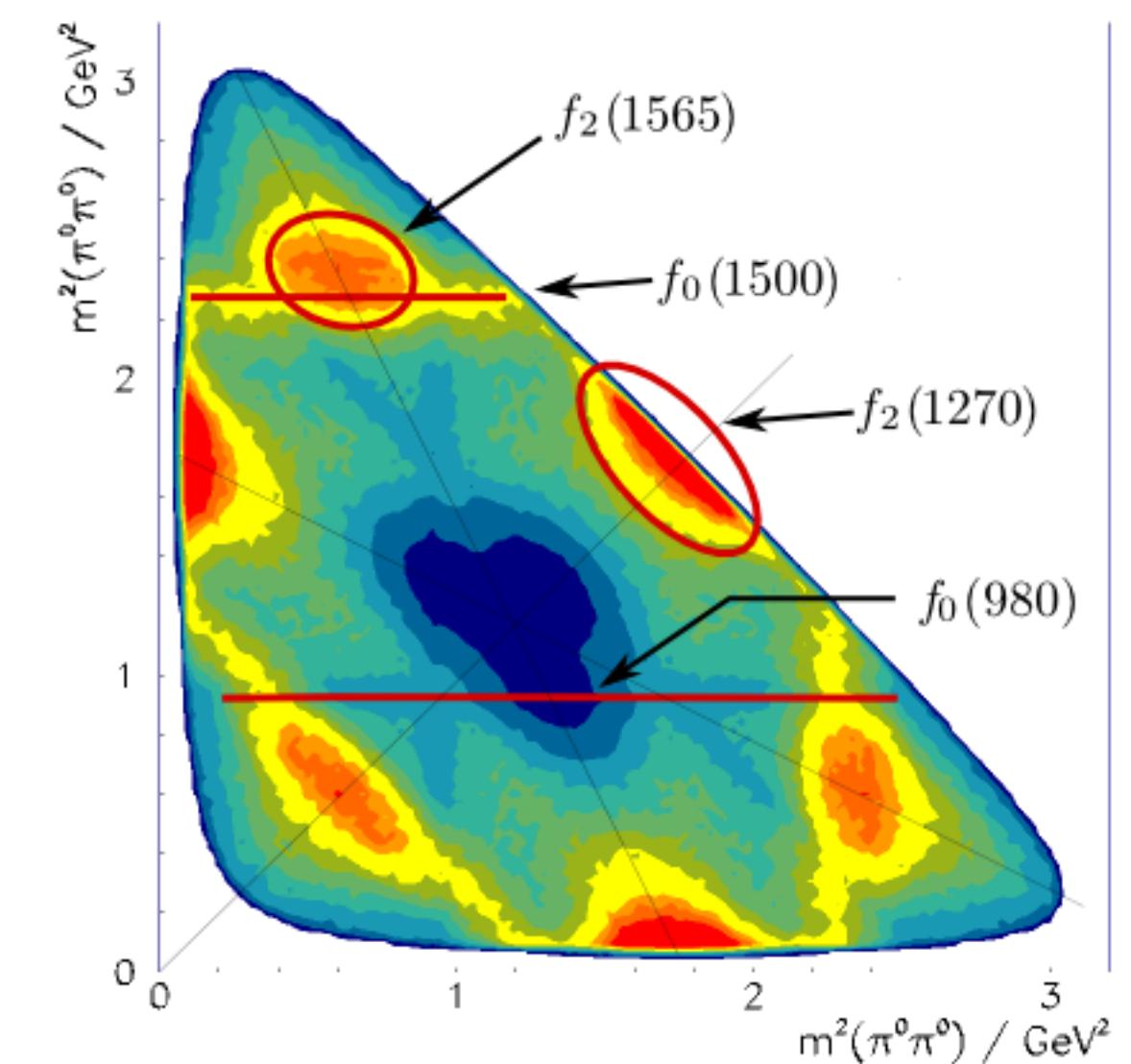
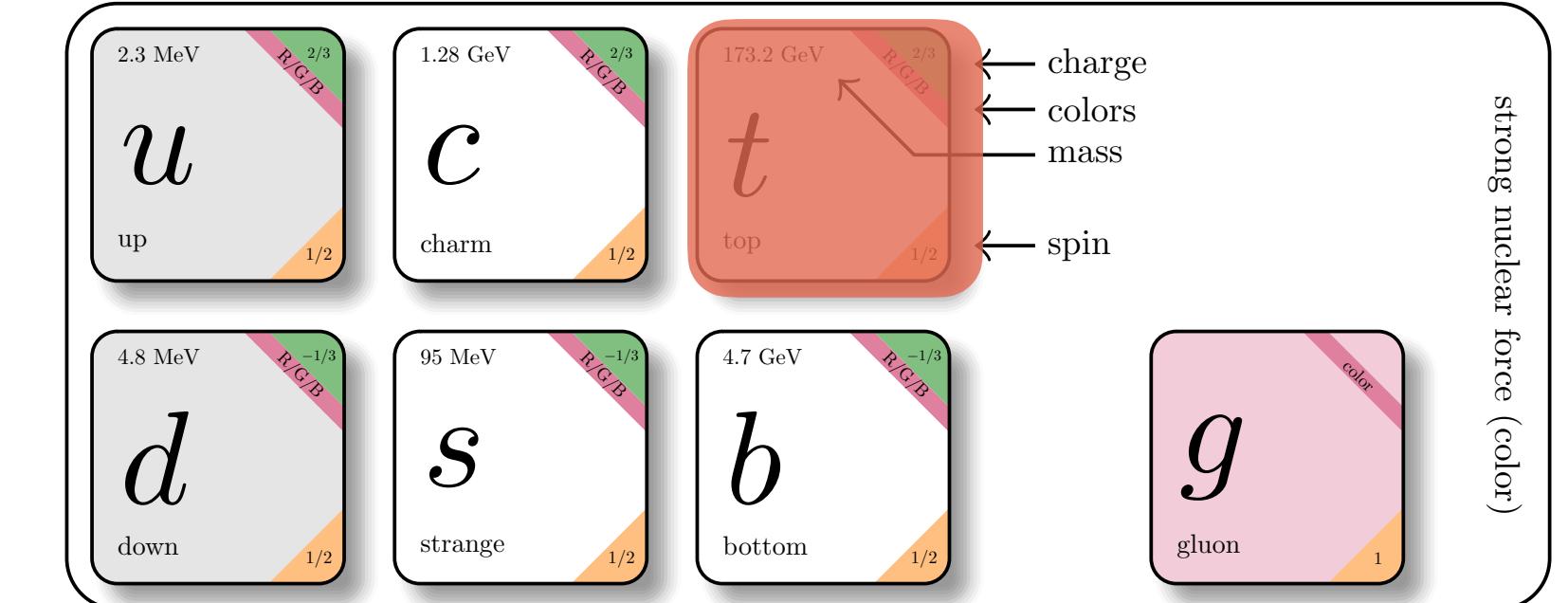
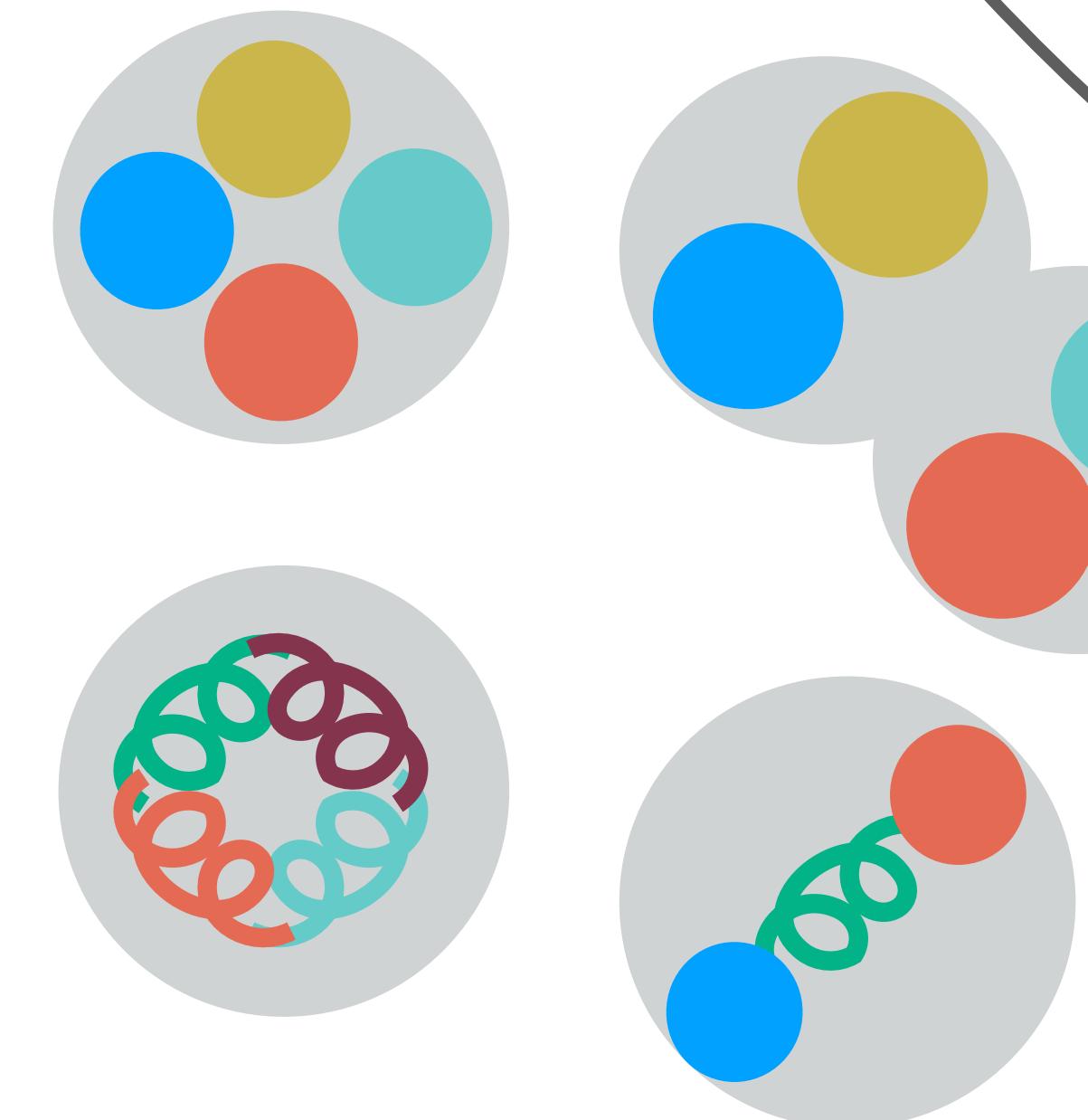


The 2015 LONG RANGE PLAN for NUCLEAR SCIENCE

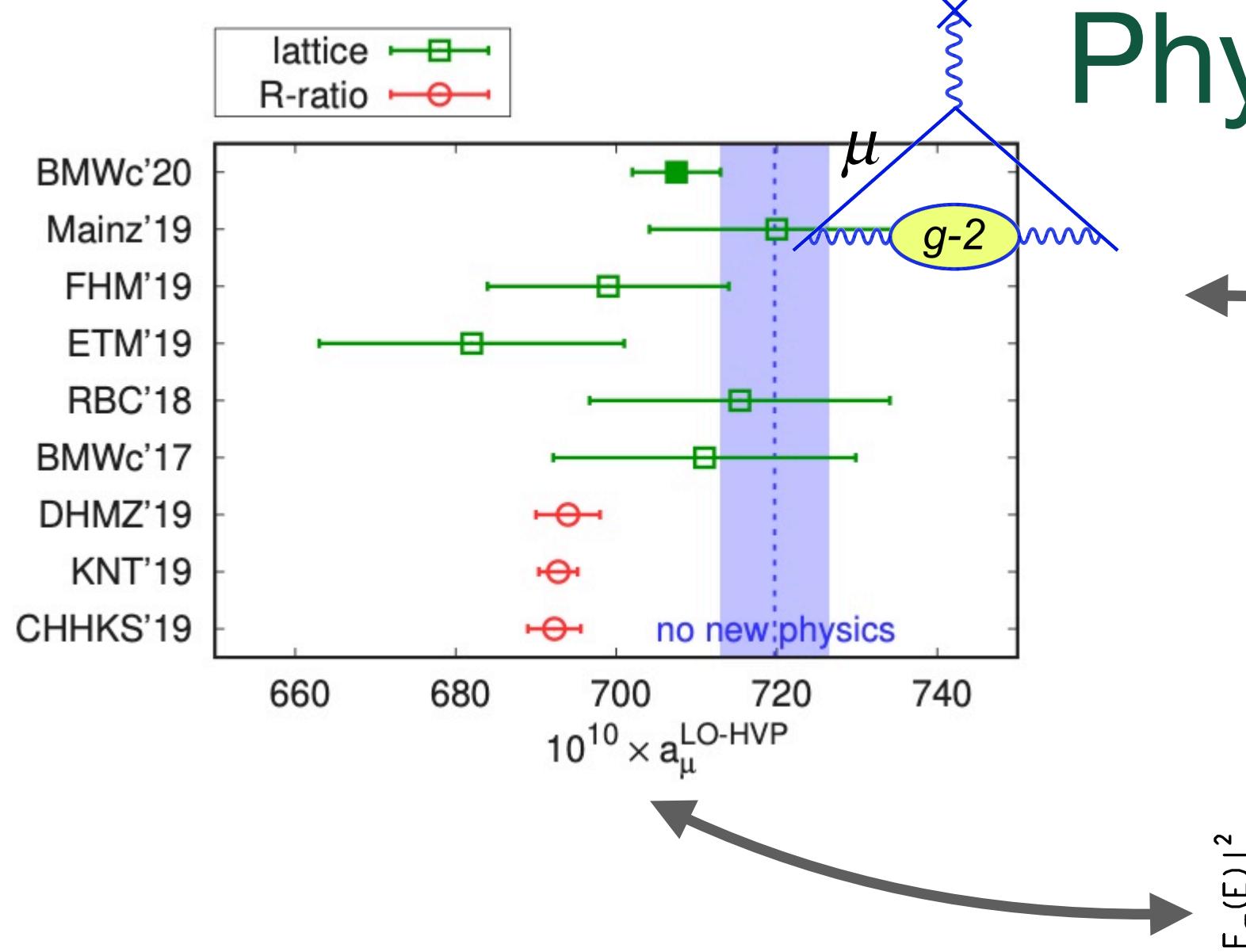


“... hadron spectroscopy
illuminates the QCD interaction
that binds quarks.”

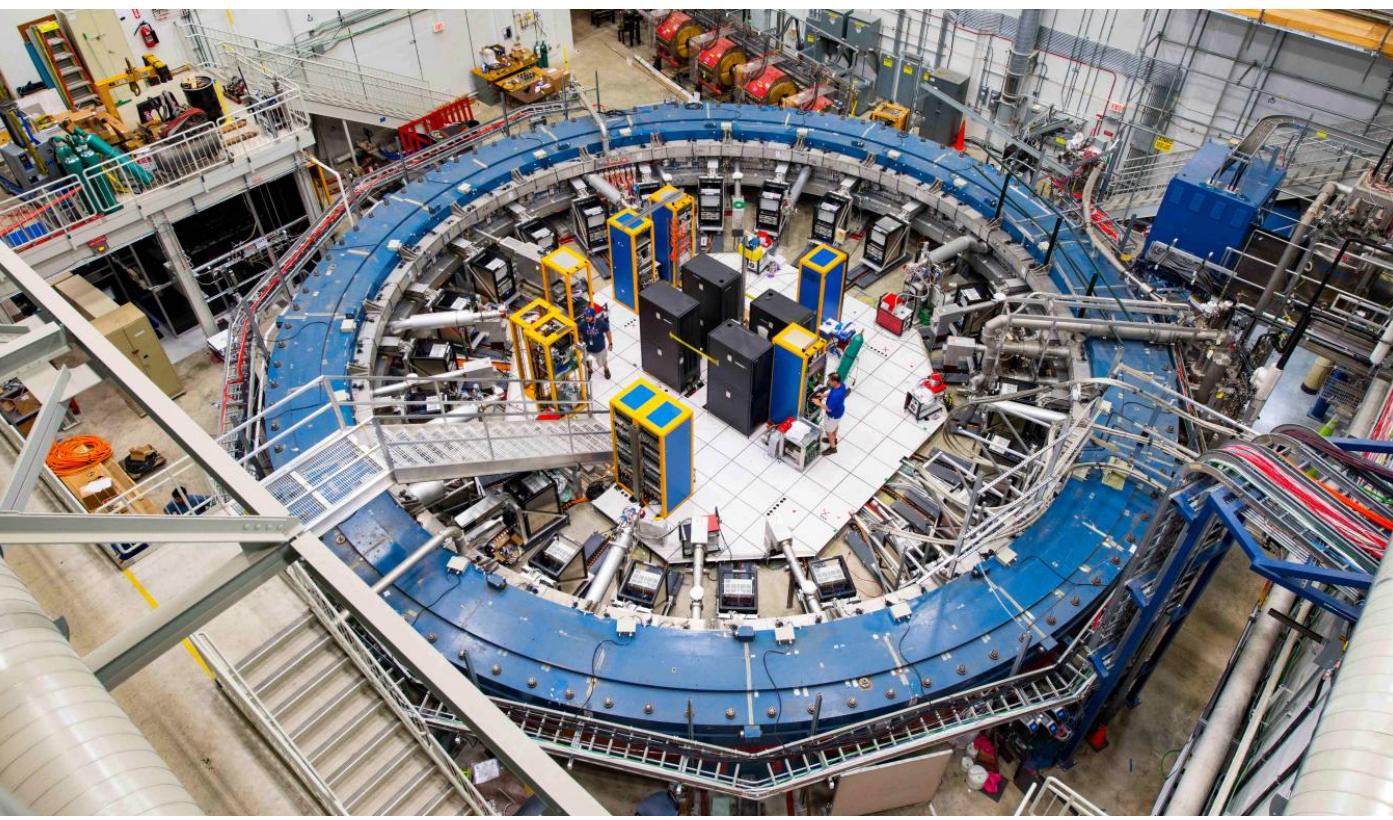
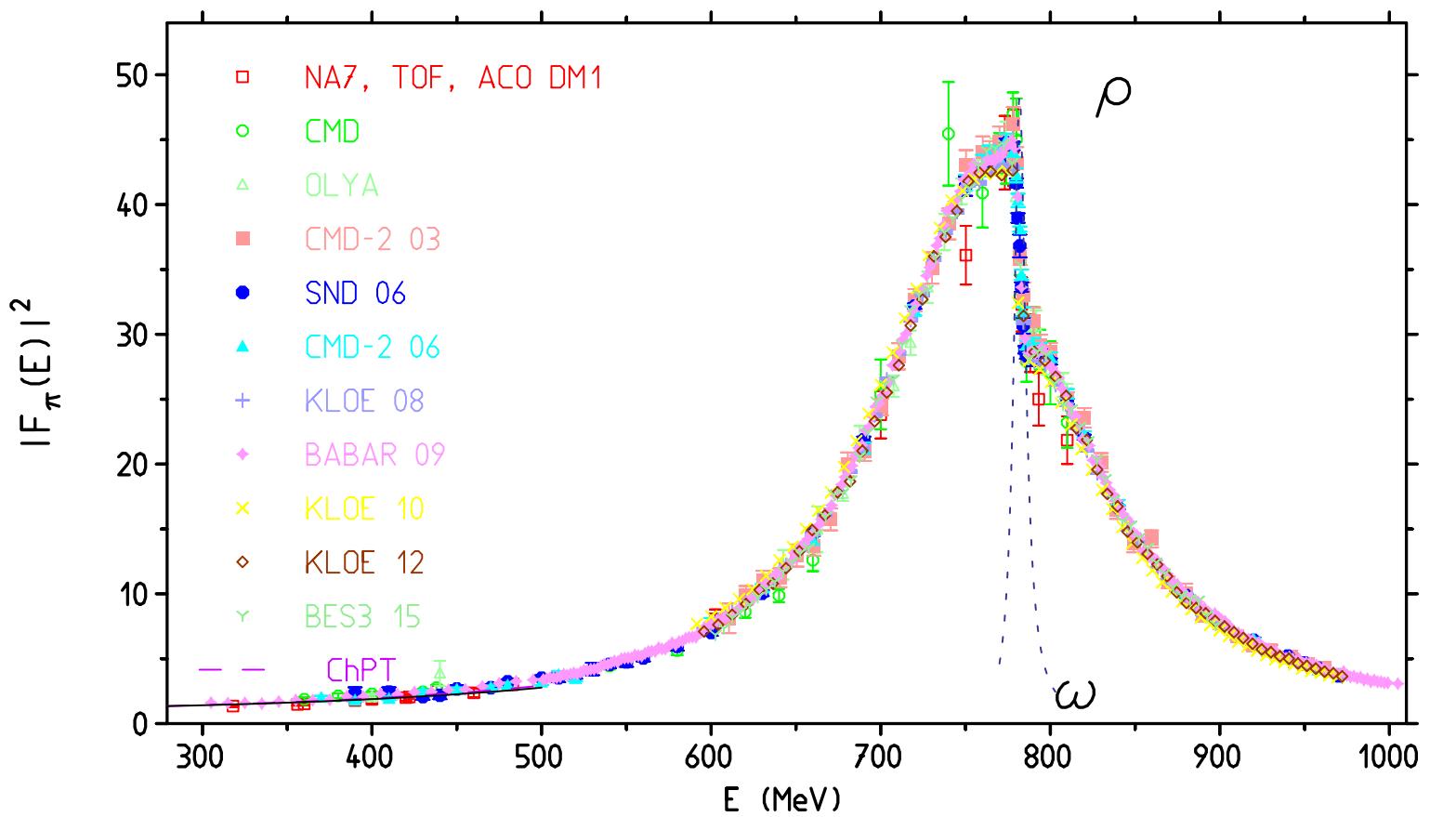
QCD



Physics beyond what's known



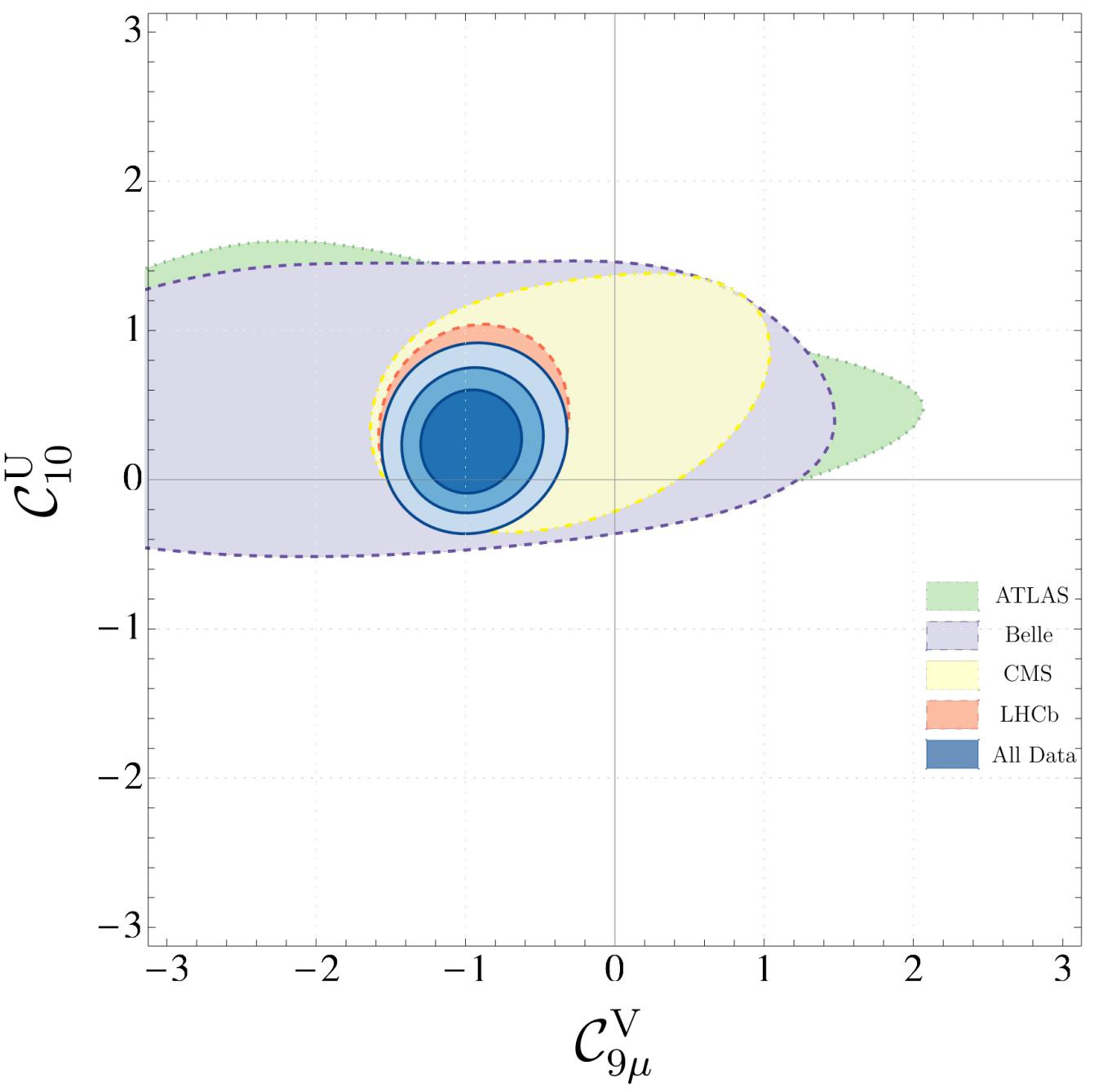
$$\sigma(e^+e^- \rightarrow \text{all})$$



Muon magnetic moment $\rightarrow (g - 2)_\mu$

Rare B decays

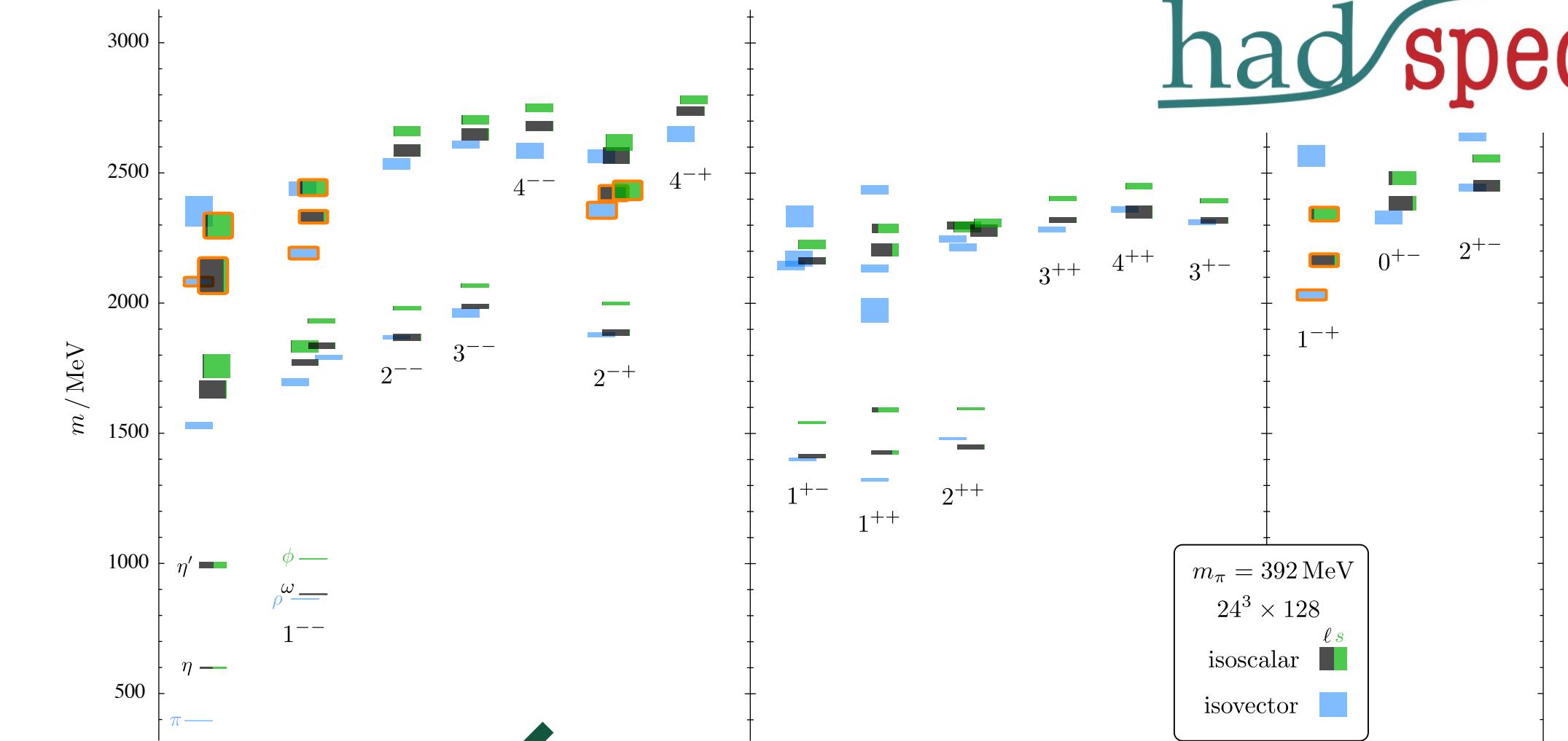
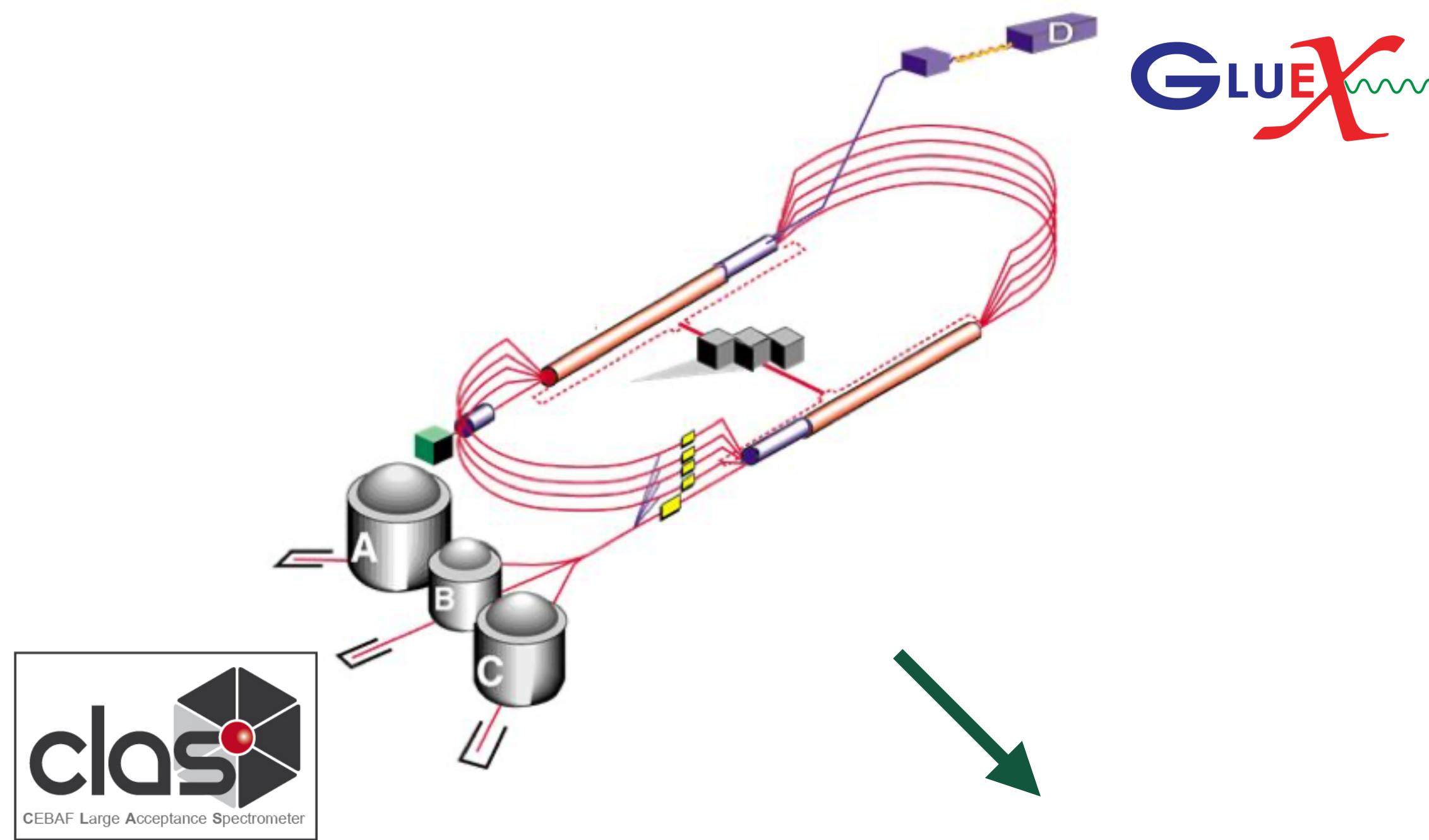
Nucleon mass dependence



Understanding the QCD spectrum



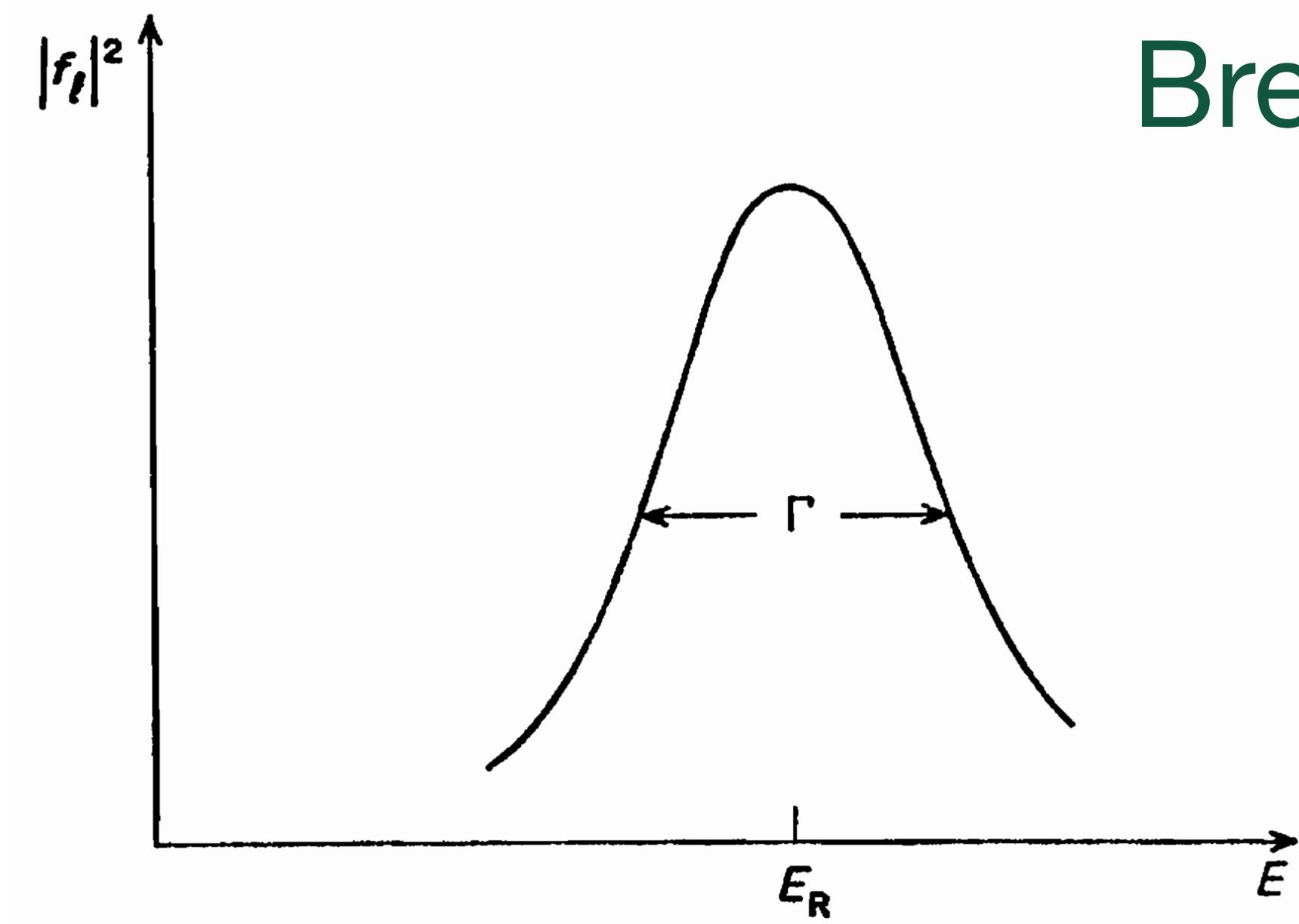
Determine the spectrum



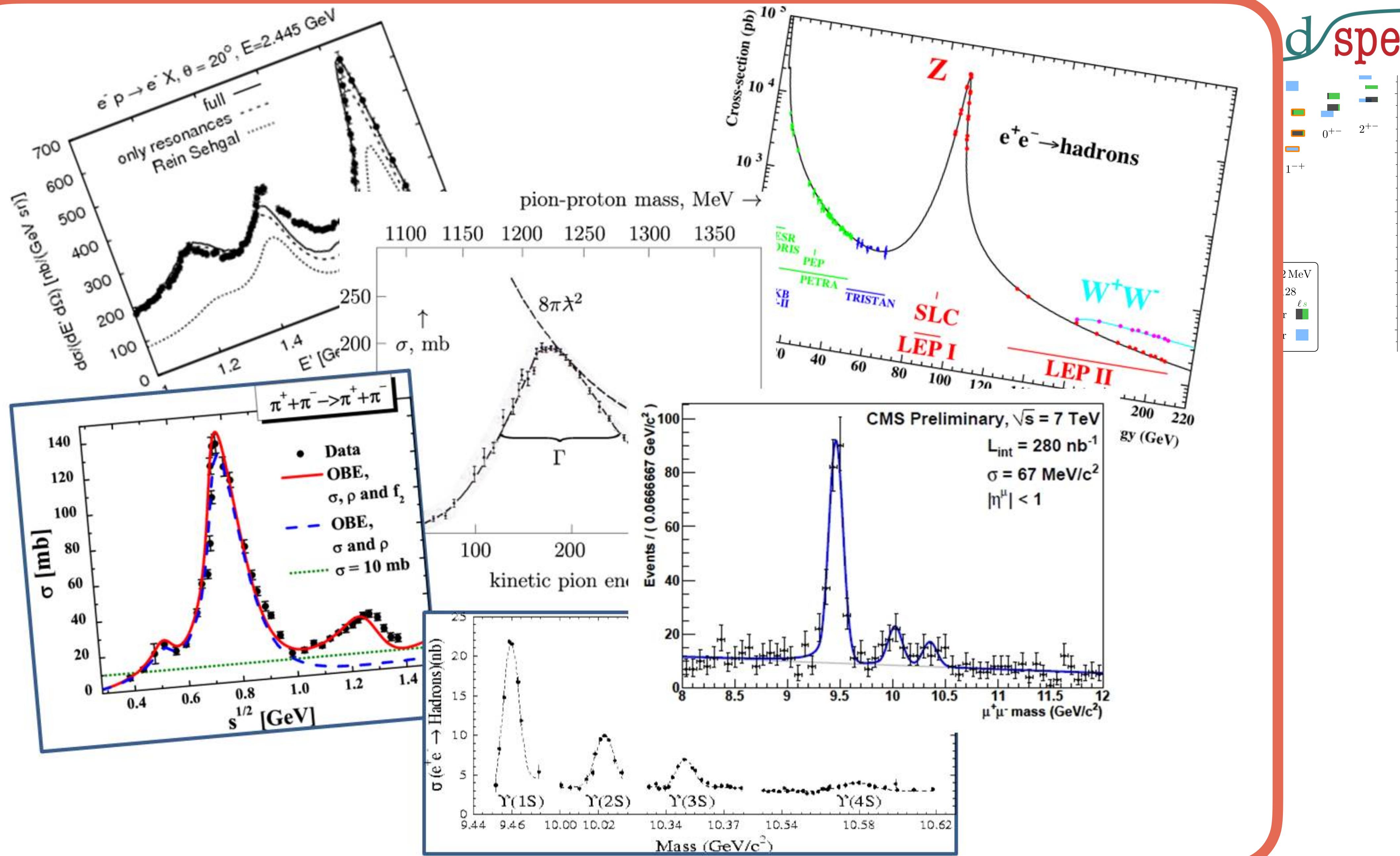
Jo's talk yesterday

Very simple

$$t_\ell(s) \simeq \frac{-M\Gamma}{M^2 - s - iM\Gamma}$$

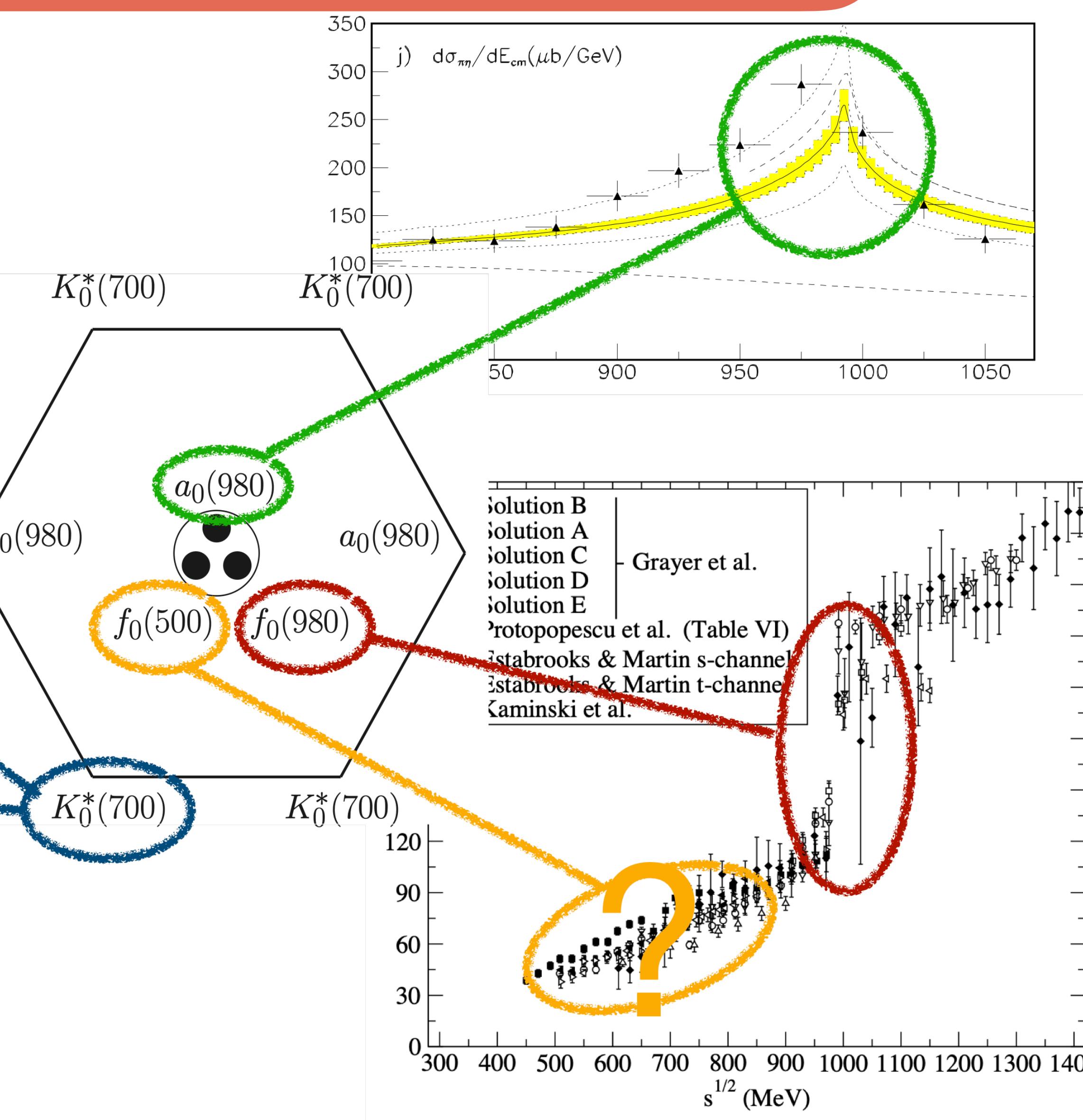
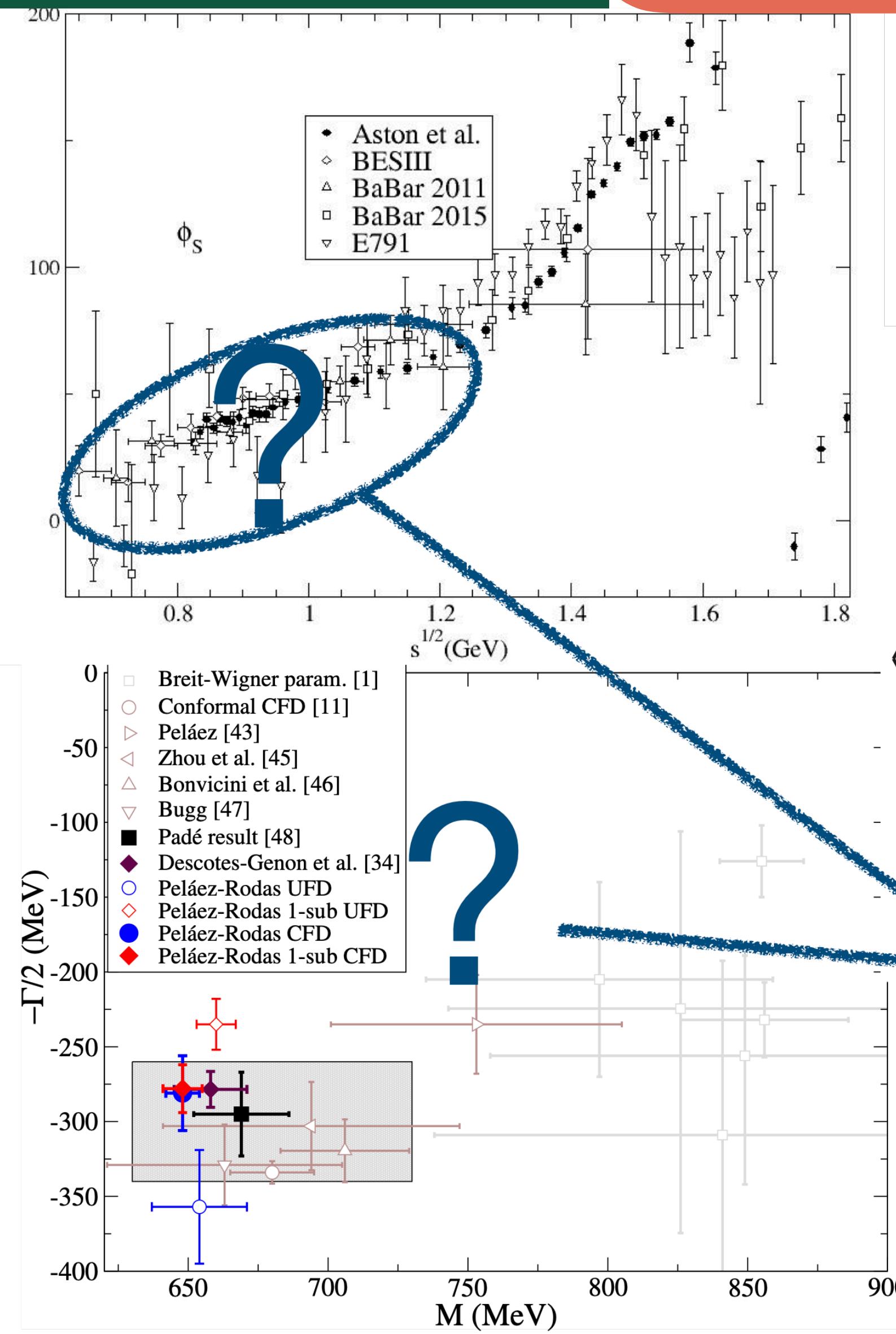


$$t_\ell(s)$$



Light Scalars

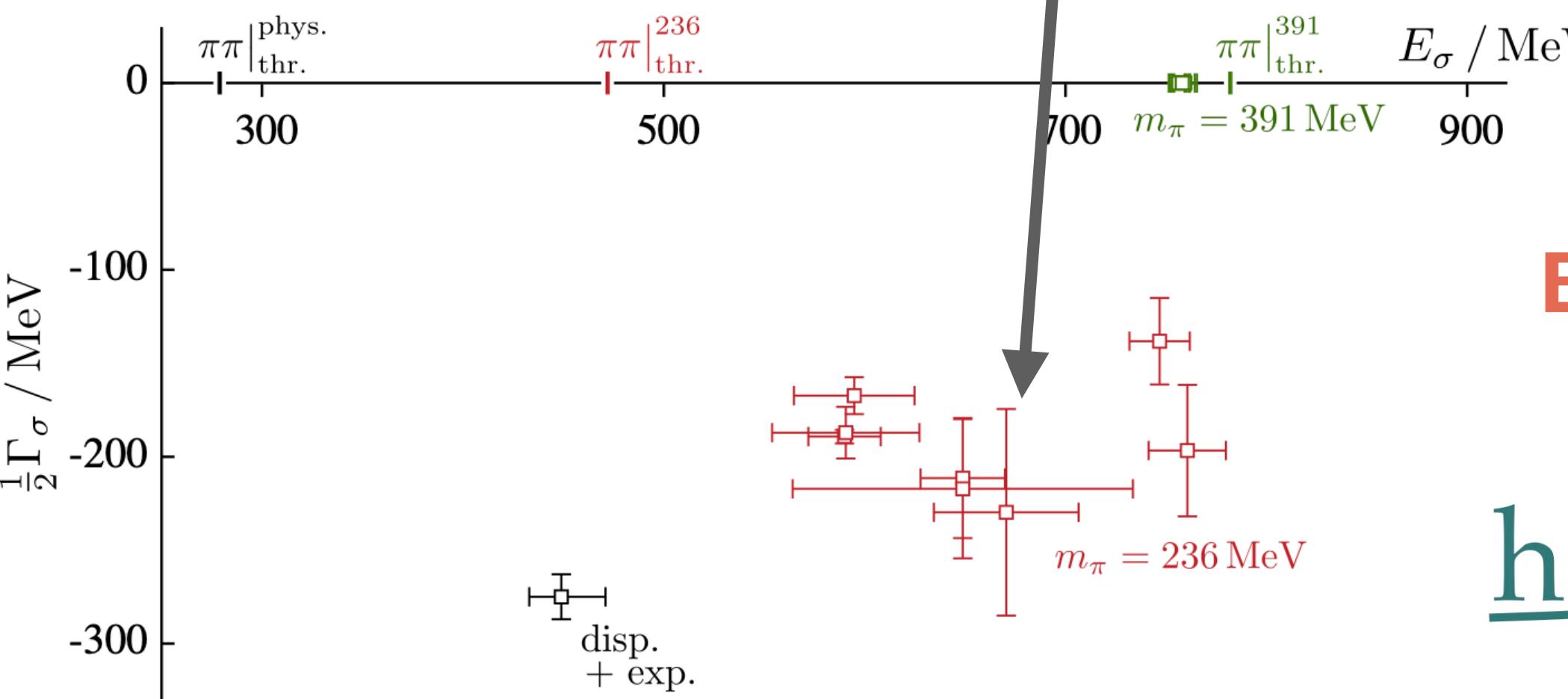
Debated for over half a century!!



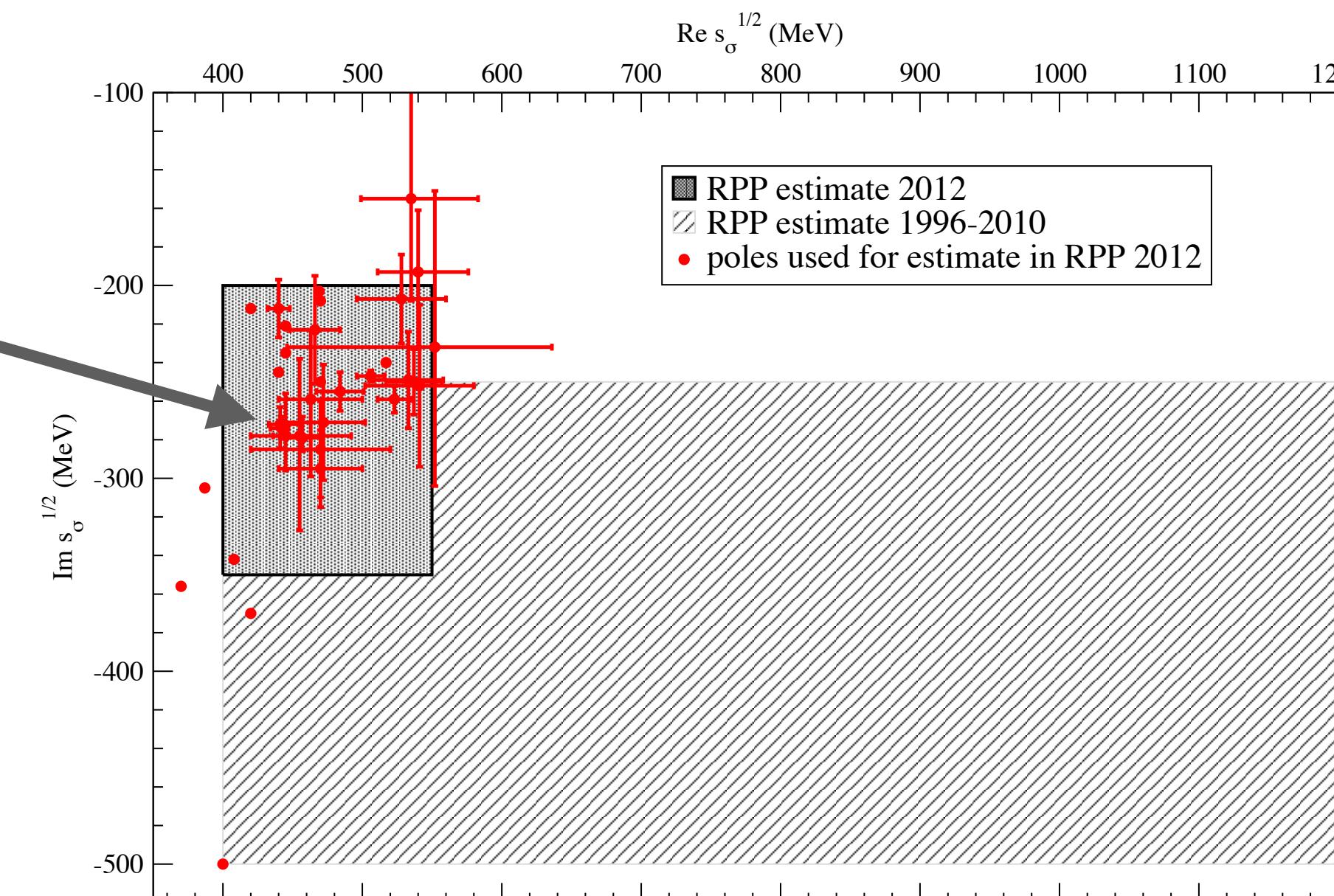
Light Scalars

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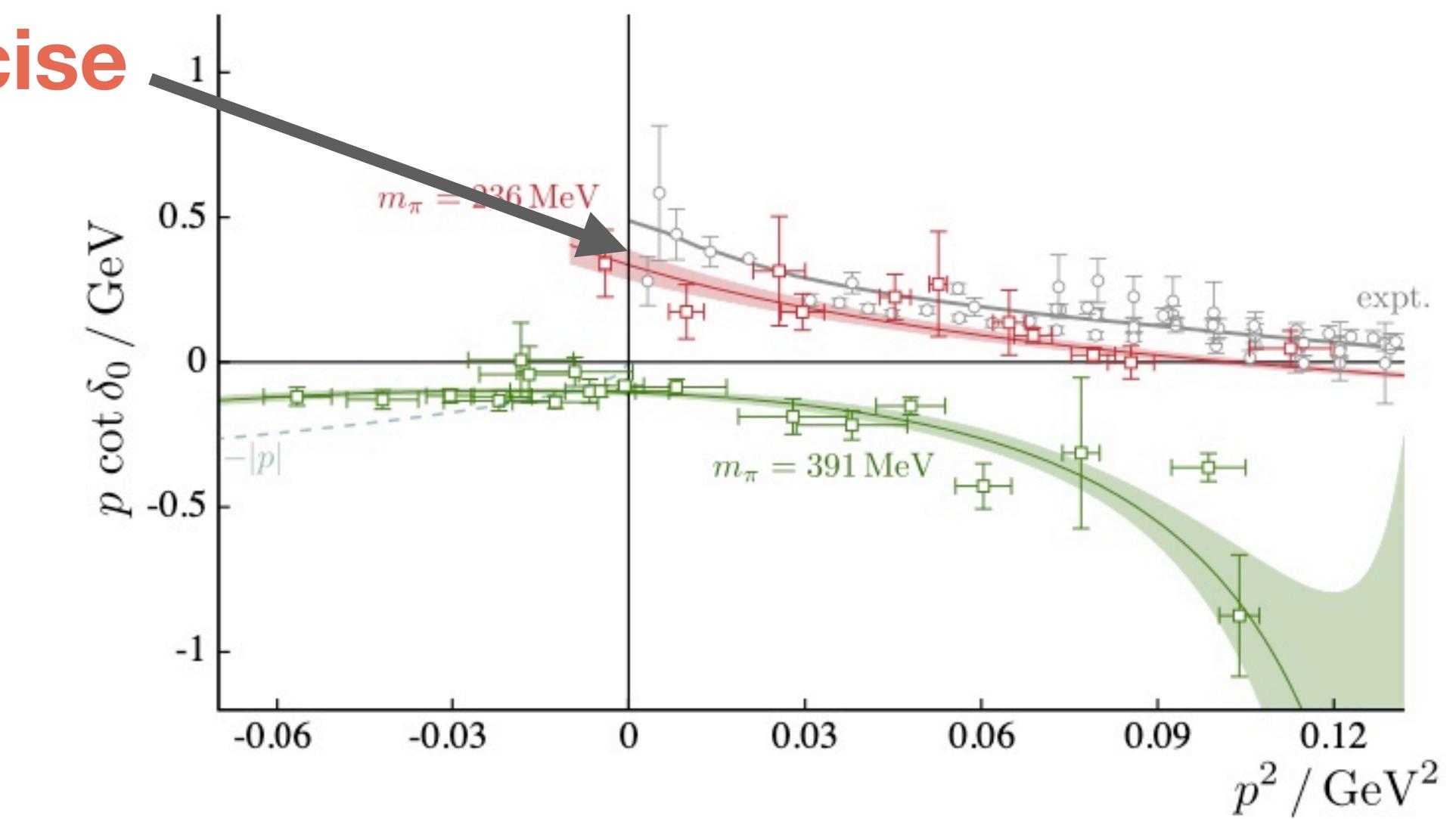
It affects both experiment
and lattice QCD



Briceño et al. 2017



But data is precise
had spec



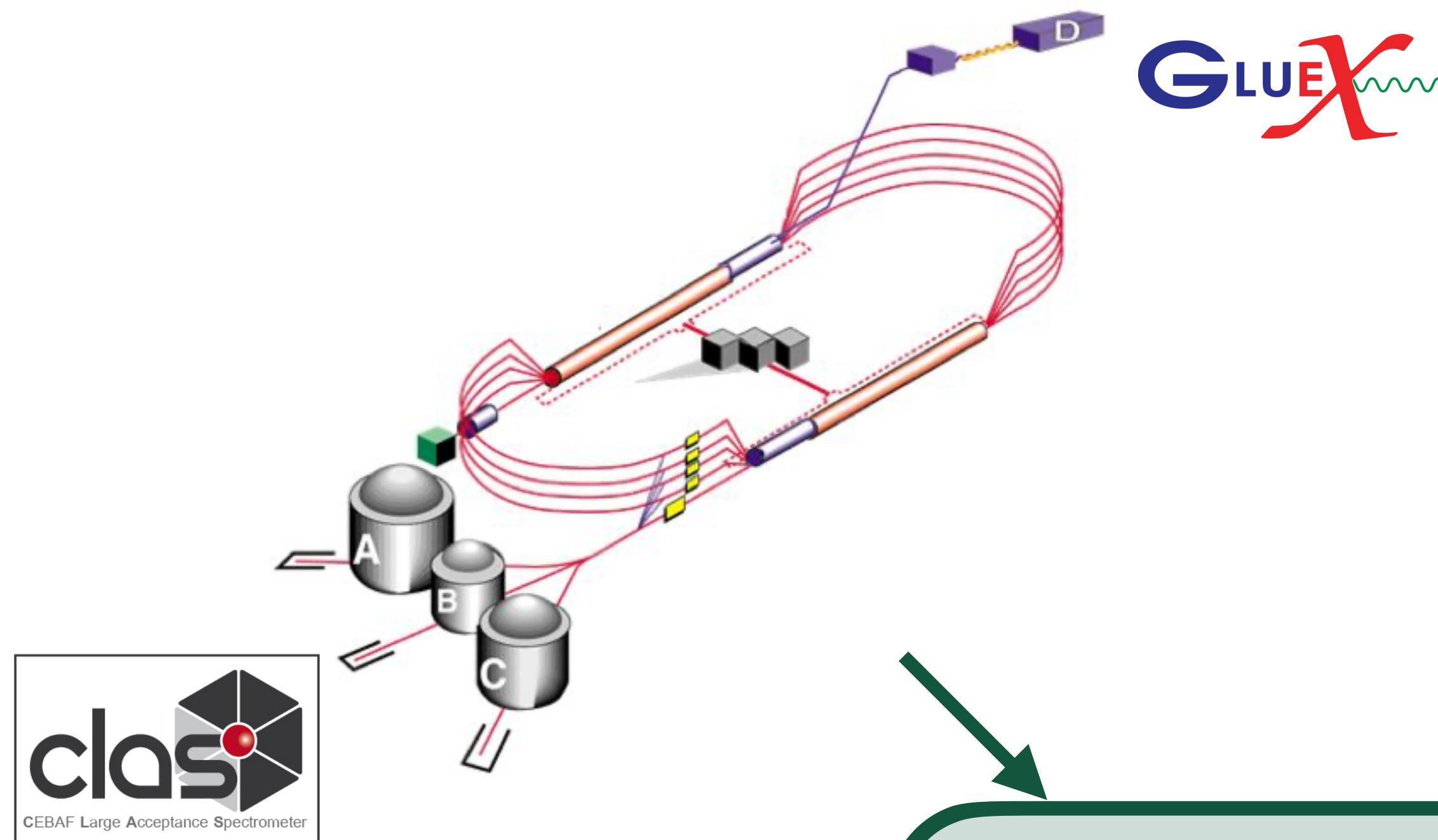
Understanding the QCD spectrum



Determine the spectrum



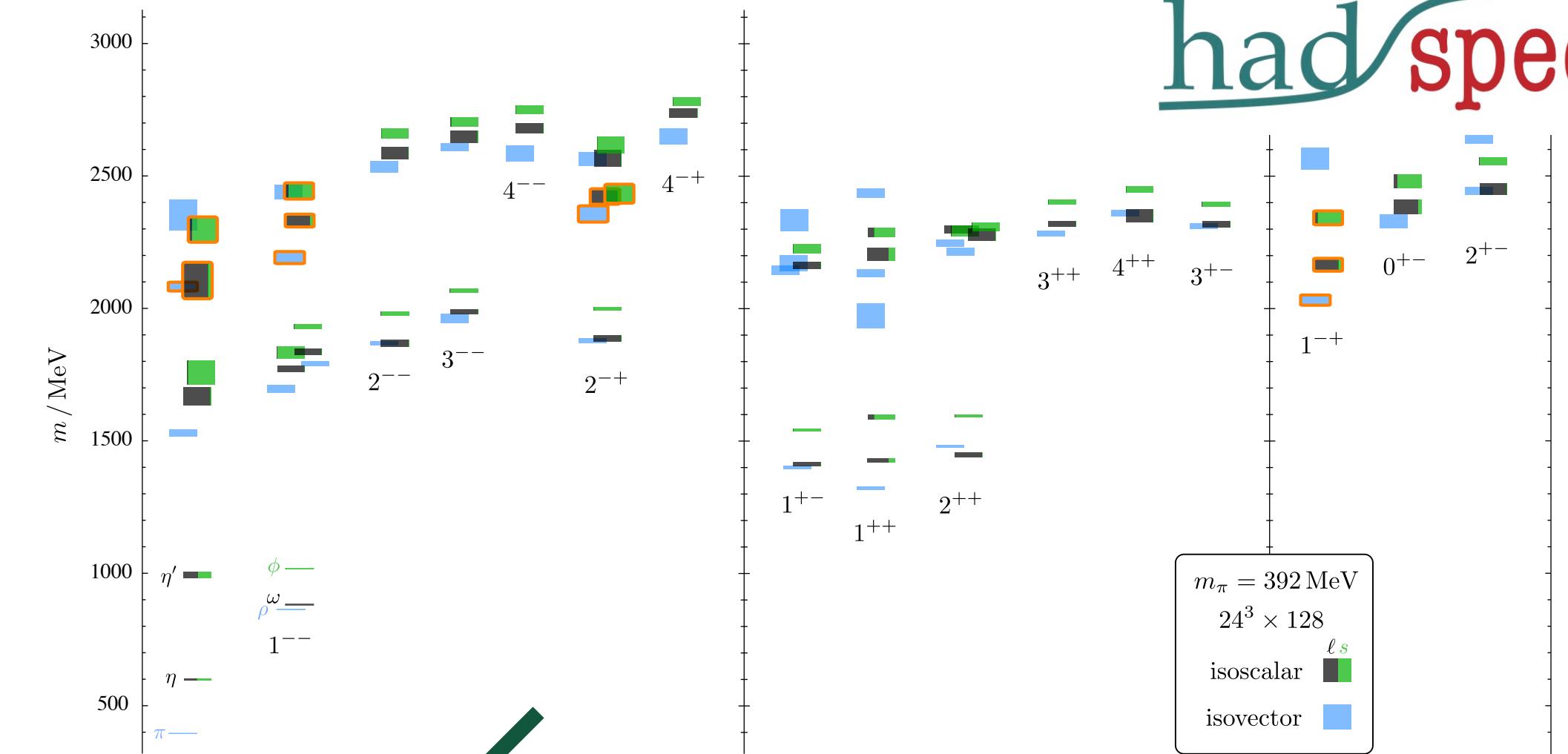
??



GLUEX



CEBAF Large Acceptance Spectrometer



had spec

Jo's talk yesterday

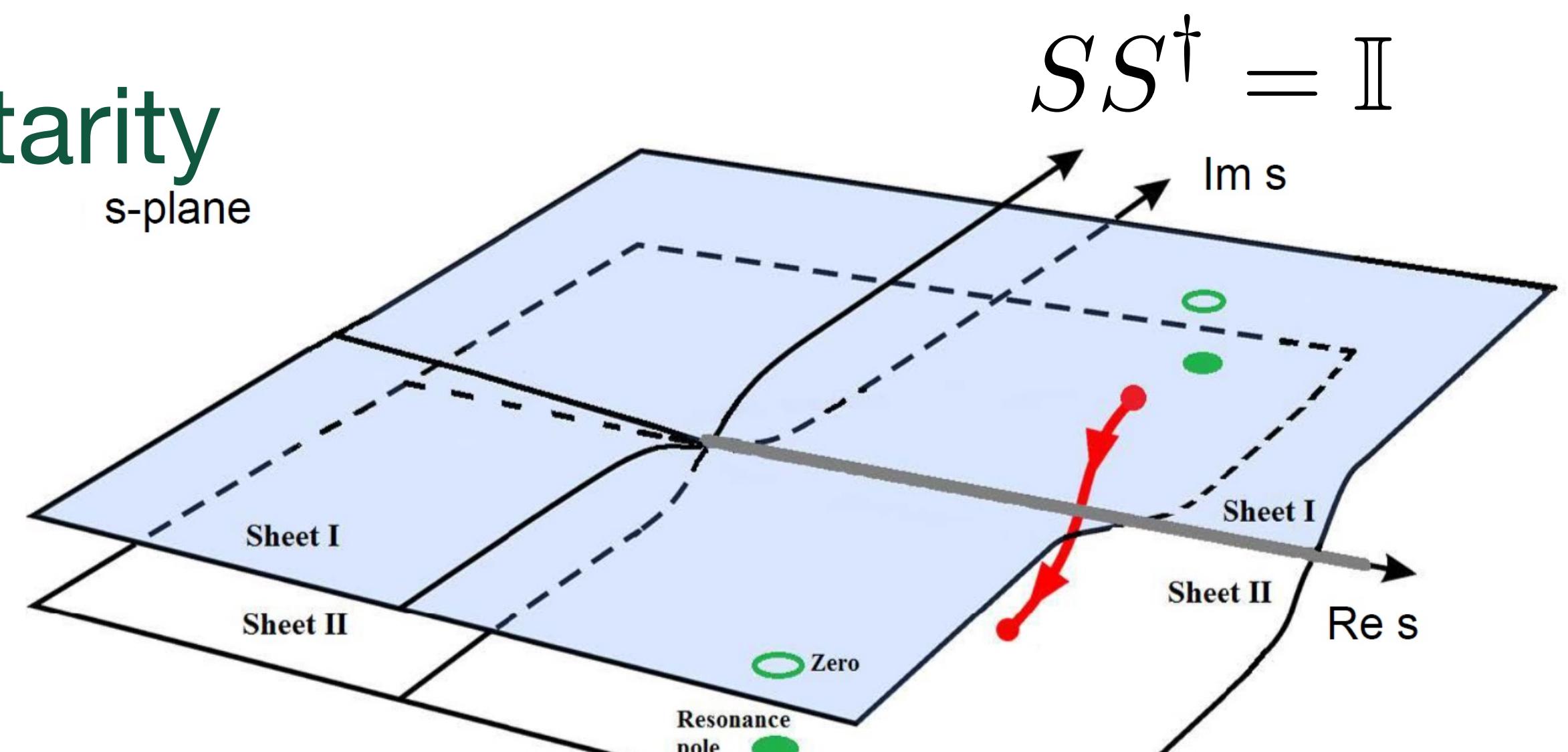
Amplitude analyses

- Unitarity
- Analyticity
- Crossing

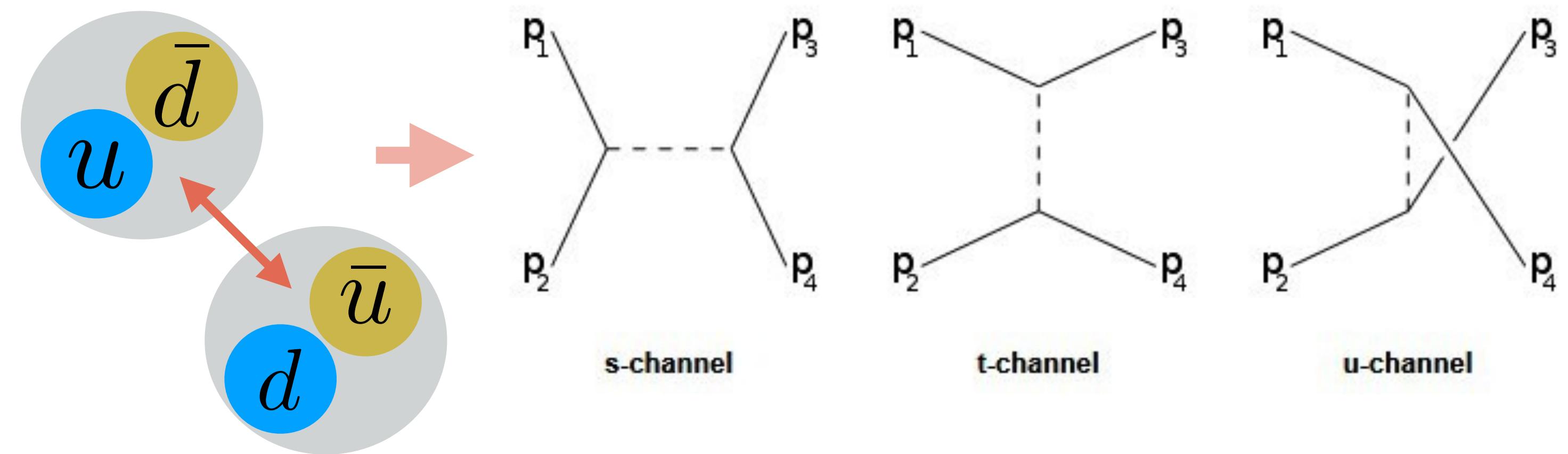
Observables

First principles

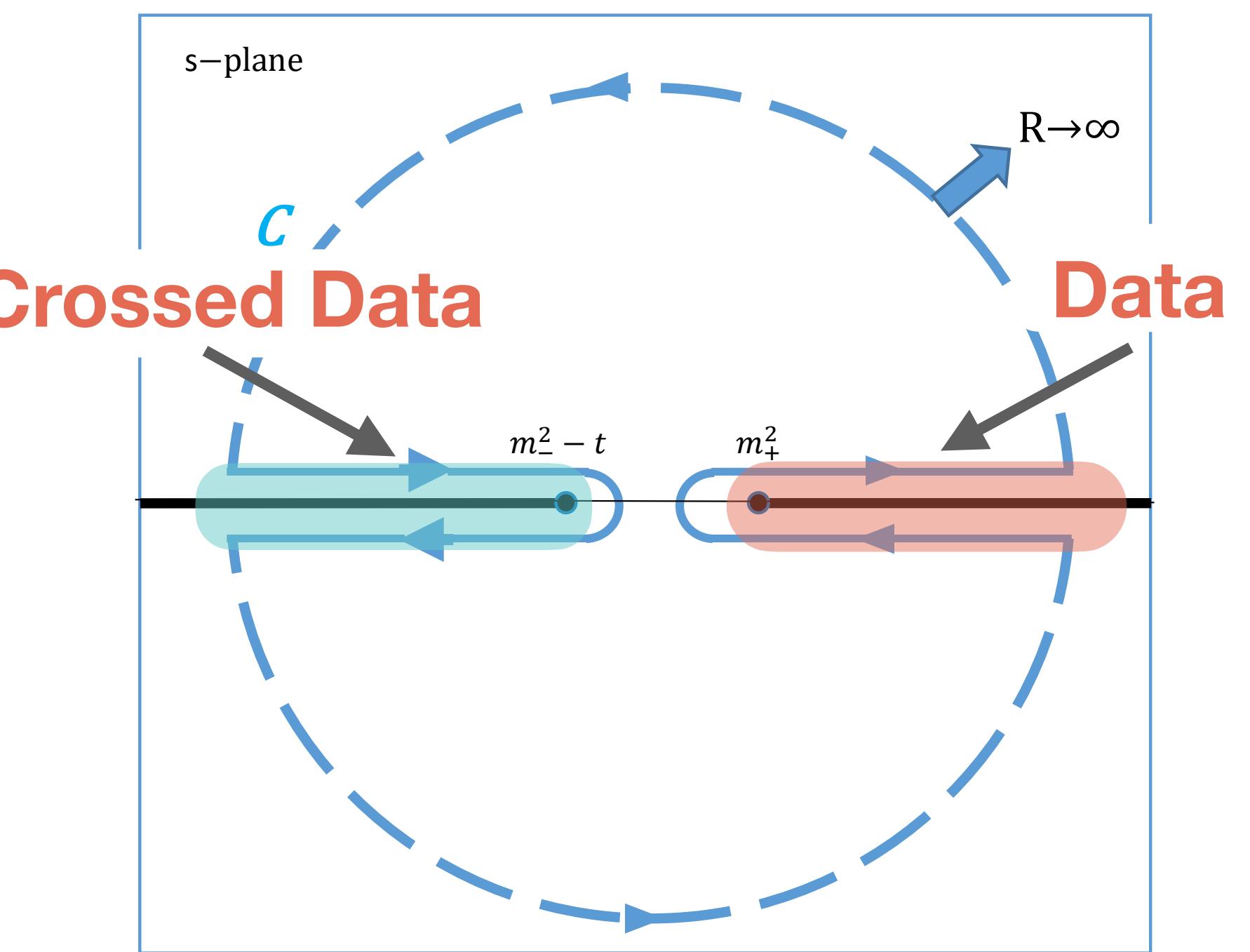
Unitarity



Crossing



Causality \leftrightarrow Analyticity



$$t(z) = \oint_C \frac{t(z')}{z' - z} dz'$$

Dispersion relations

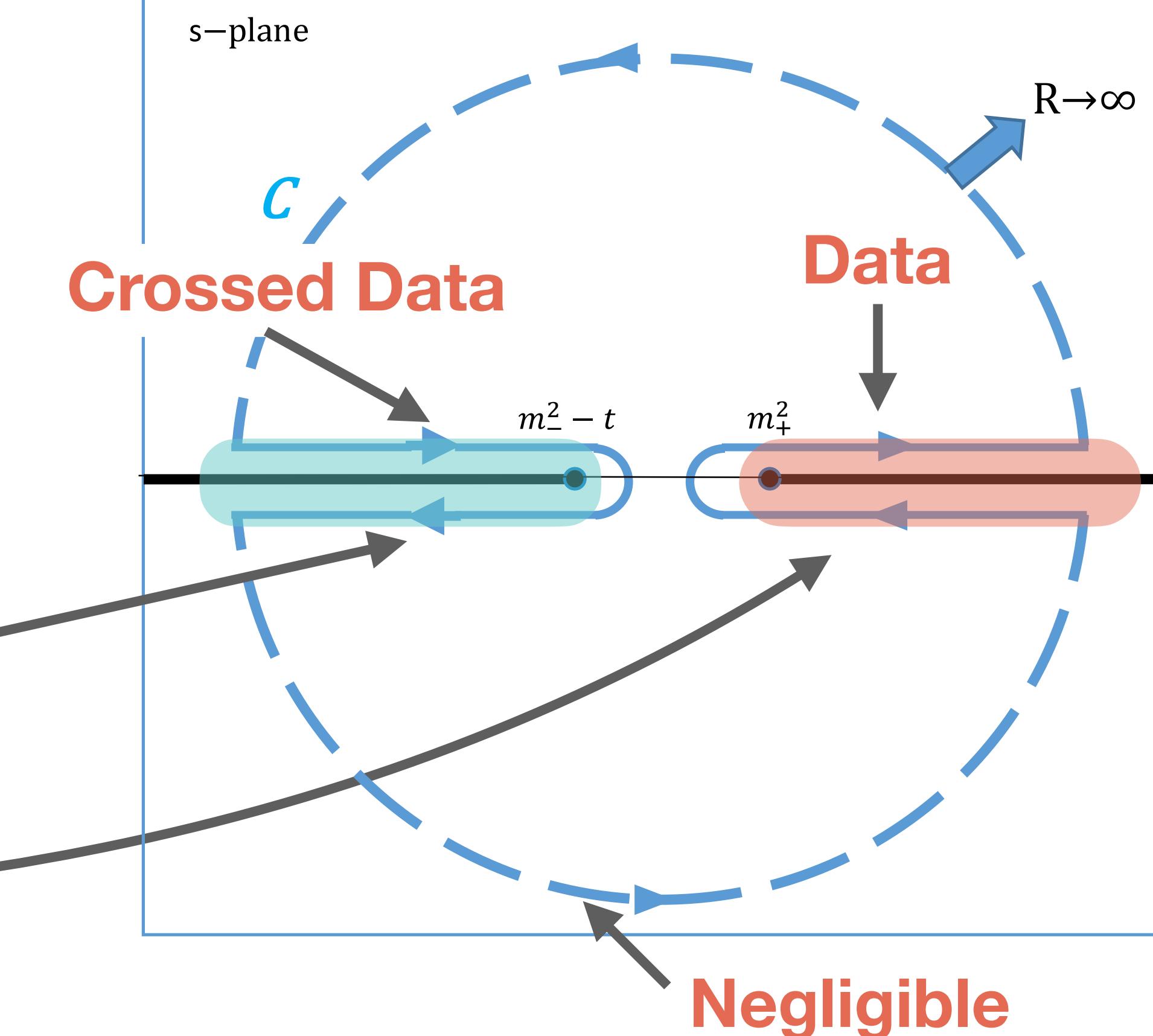
Cauchy

$$t(z) = \oint_C \frac{t(z')}{z' - z} dz'$$

$$F(s, t) = \frac{1}{\pi} \int_{s_{th}}^{\infty} ds' \frac{\text{Im } F(s', t)}{s' - s} + LHC$$

Crossing

$$F(s, t) = \frac{1}{\pi} \int_{s_{th}}^{\infty} ds' \left(\frac{\text{Im } F(s', t)}{(s' - s)} + \frac{\sum C_{su}^{I'} \text{Im } F^{I'}(s', t)}{(s' - u)} \right)$$



Fit → *In*

DR → *Out*

$$F(s, t) = \frac{1}{\pi} \int_{s_{th}}^{\infty} ds' \left(\frac{\text{Im} F(s', t)}{(s' - s)} + \frac{\sum C_{su}^{I'} \text{Im} F^{I'}(s', t)}{(s' - u)} \right)$$

$$F(s, t) = 16K\pi \sum_{\ell} (2\ell + 1) P_{\ell}(\cos \theta) f_{\ell}(s)$$

Model-independent

- Obtain your DRs
- Use all data available
- Prune/fit data

Amplitude analyses

- Unitarity
- Analiticity
- Crossing

- Make *Fit* → *In* *DR* → *Out* compatible

πK scattering

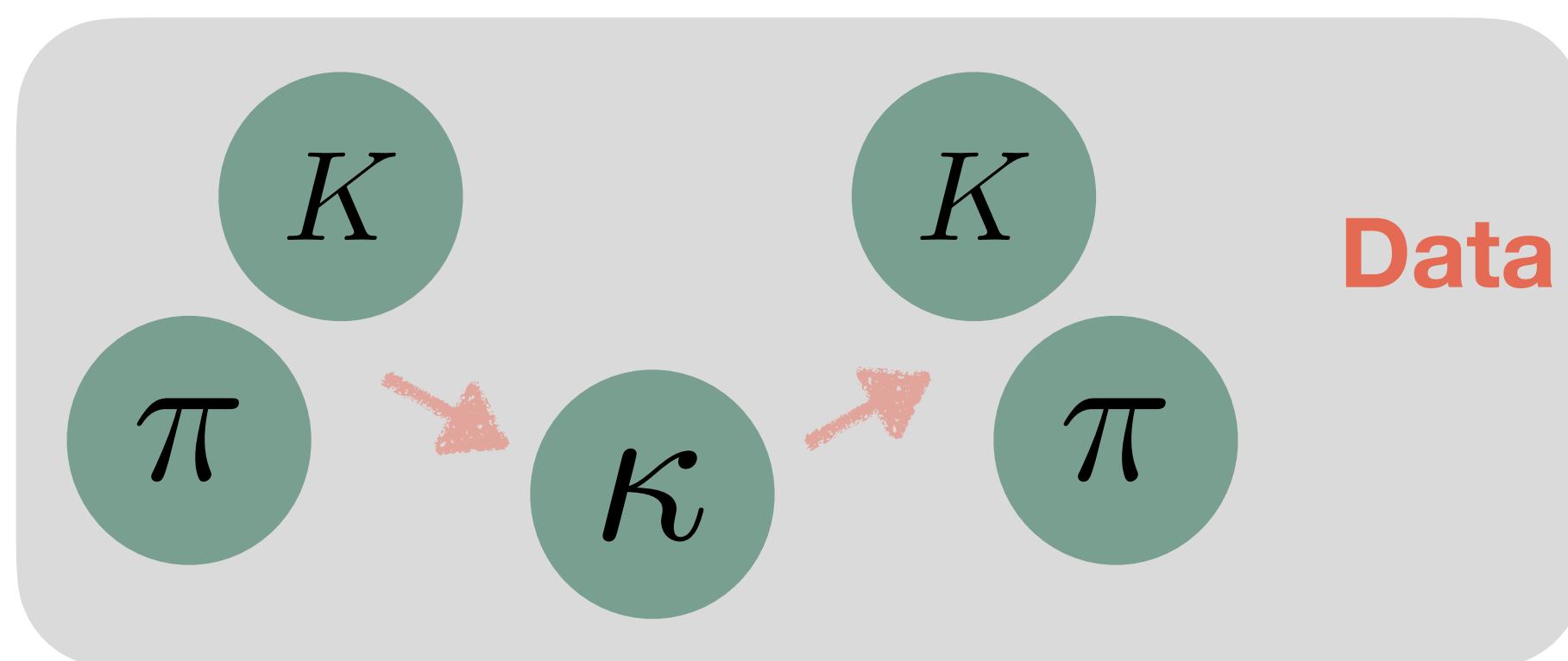


Obtain your DRs

Fit \rightarrow In

DR \rightarrow Out

$$F^+(s) = F^+(s_{th}) + \frac{(s - s_{th})}{\pi} \int_{s_{th}}^{\infty} ds' \left[\frac{ImF^+(s')}{(s' - s)(s' - s_{th})} + \frac{ImF^+(s')}{(s' + s - 2\Sigma_{\pi K})(s' + s_{th} - 2\Sigma_{\pi K})} \right]$$



πK scattering

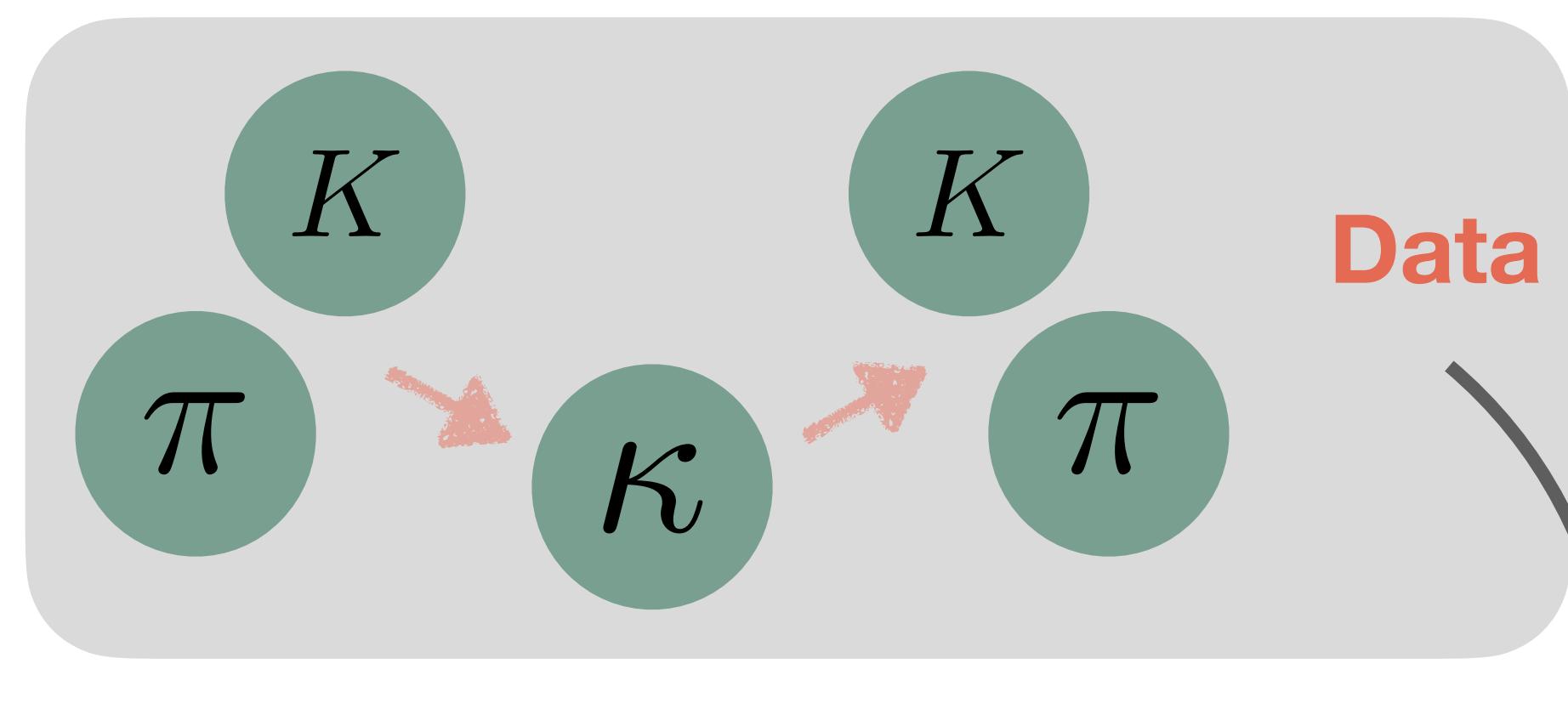


Obtain your DRs

Fit → In

DR → Out

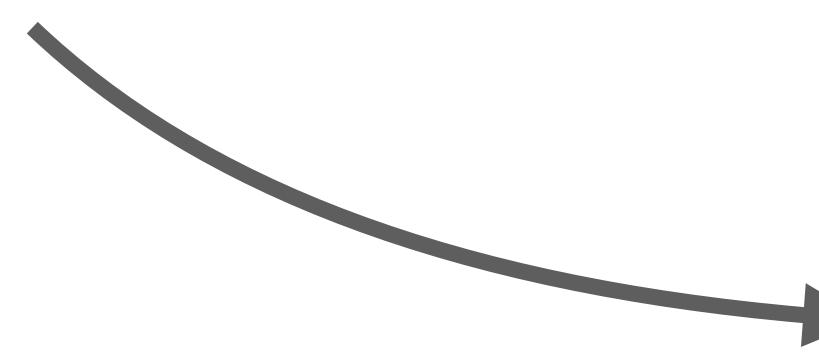
$$F^+(s) = F^+(s_{th}) + \frac{(s - s_{th})}{\pi} \int_{s_{th}}^{\infty} ds' \left[\frac{ImF^+(s')}{(s' - s)(s' - s_{th})} + \frac{ImF^+(s')}{(s' + s - 2\Sigma_{\pi K})(s' + s_{th} - 2\Sigma_{\pi K})} \right]$$



Partial waves

$$f_\ell^I(s) = \frac{1}{\rho(s) \cot \delta_\ell^I(s) - i\rho(s)}$$

Unitarity



$$F^I(s, t) = 16\pi \sum_\ell (2\ell + 1) P_\ell(\cos \theta) f_\ell^I(s)$$

Remember?

$$\cot \delta_\ell^I(s) = \frac{\sqrt{s}}{2q^{2\ell+1}} \sum B_n \omega(s)^n$$

πK scattering



Make

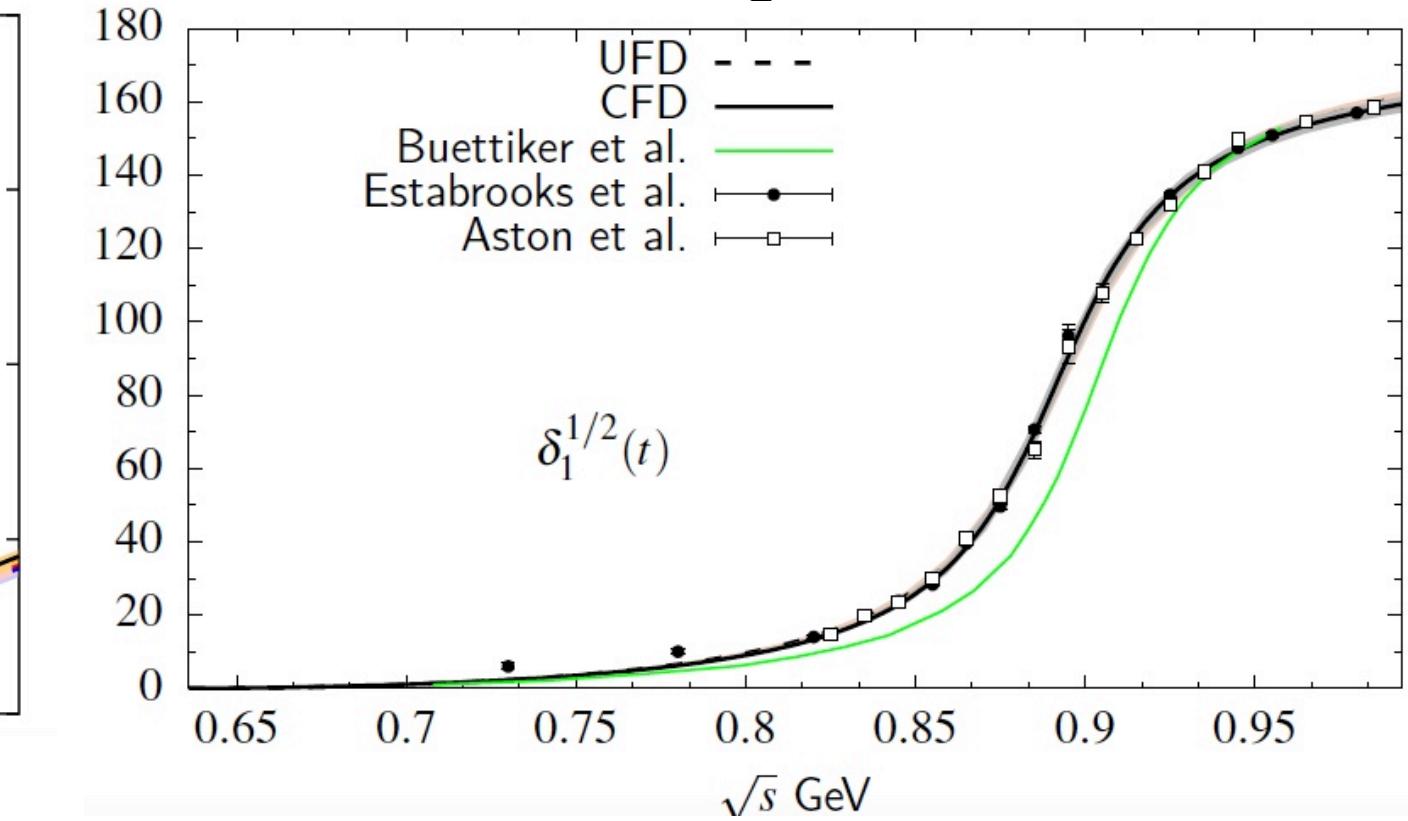
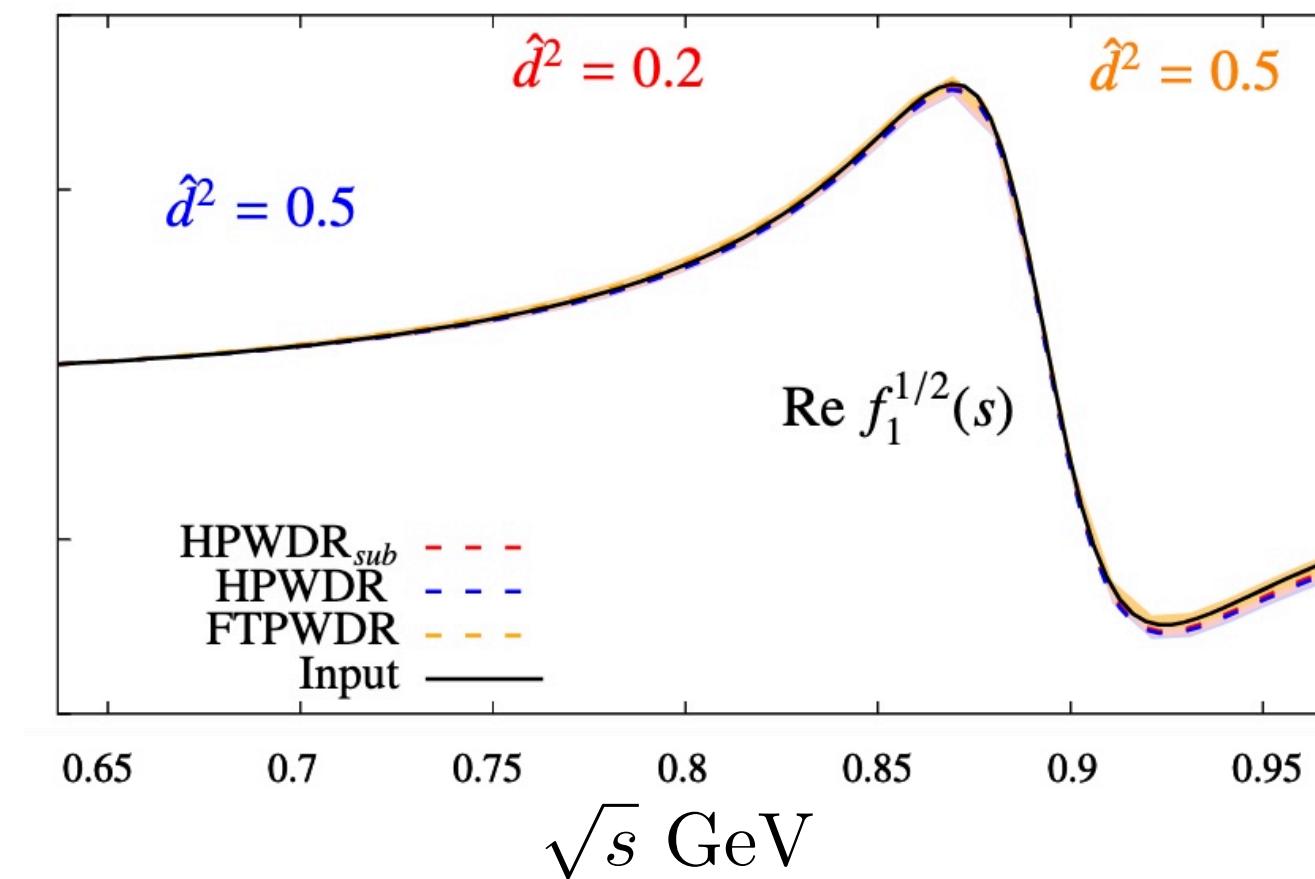
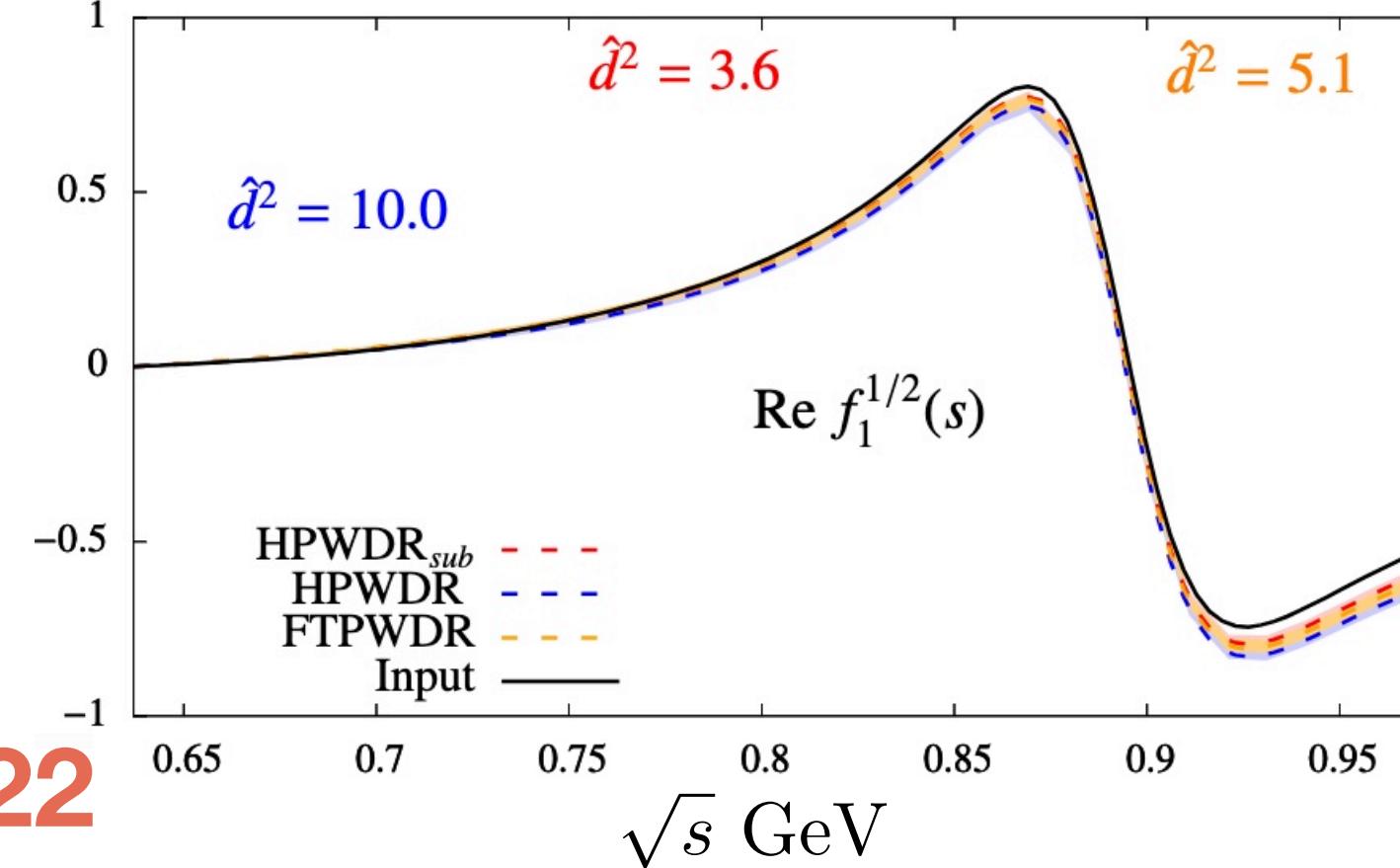
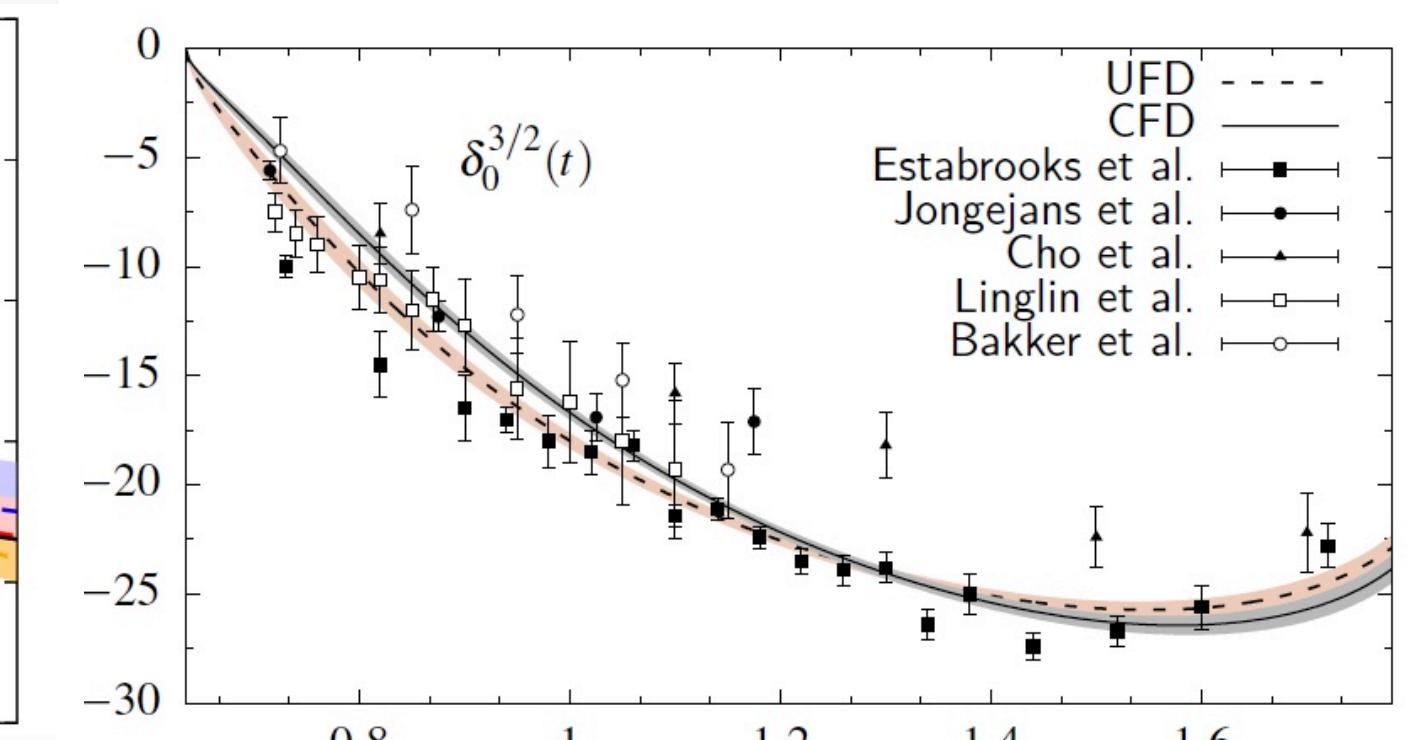
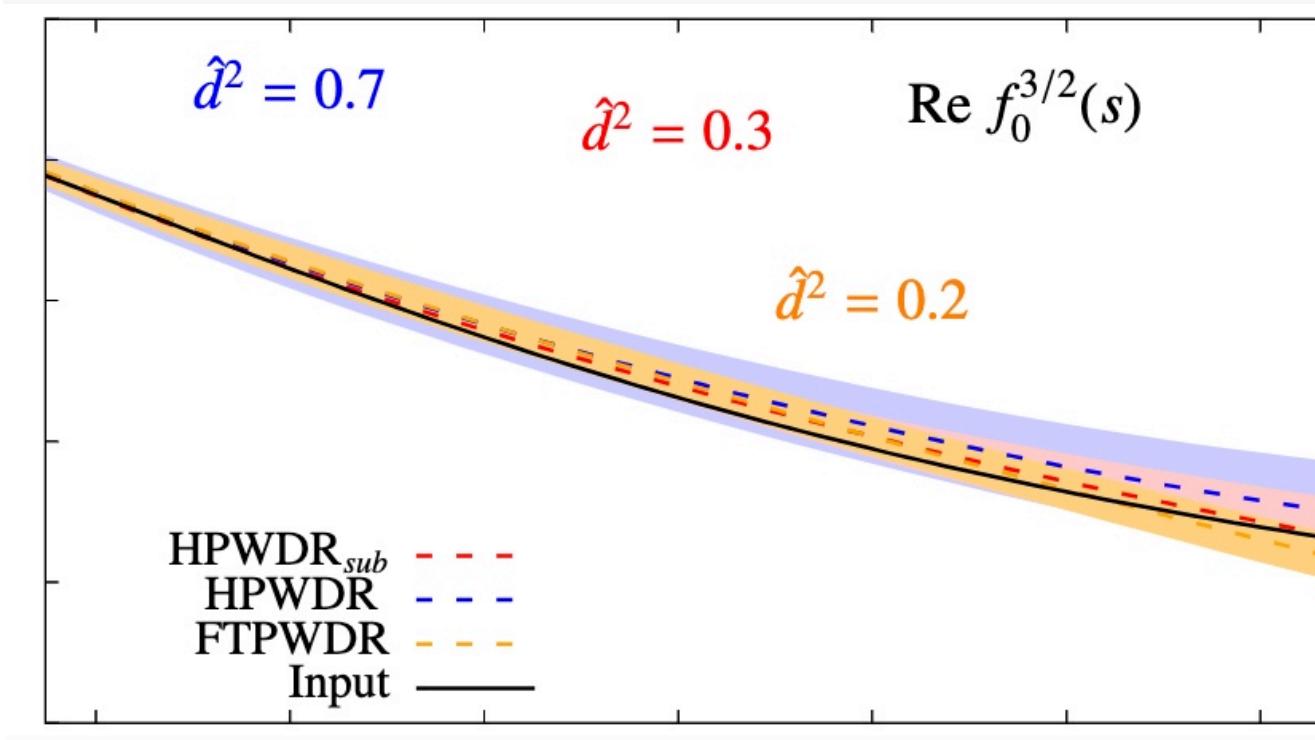
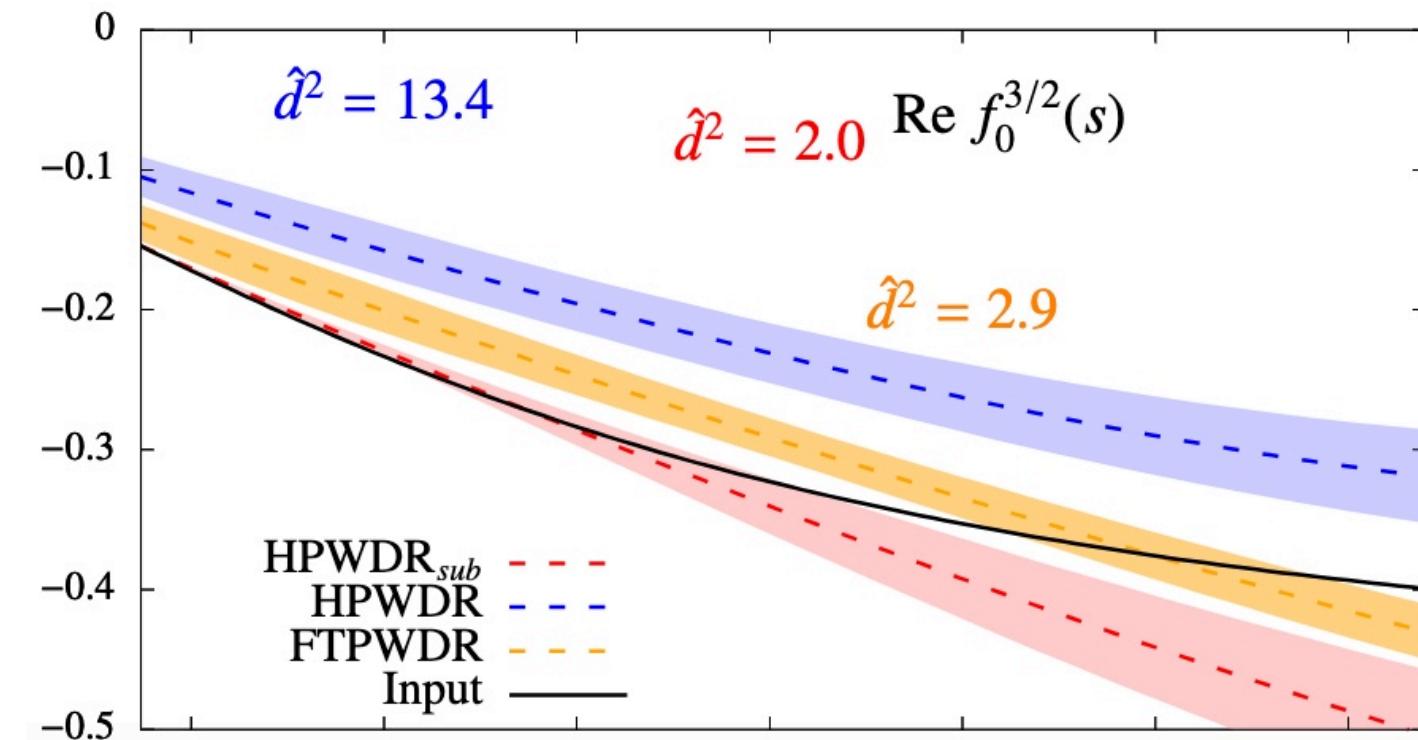
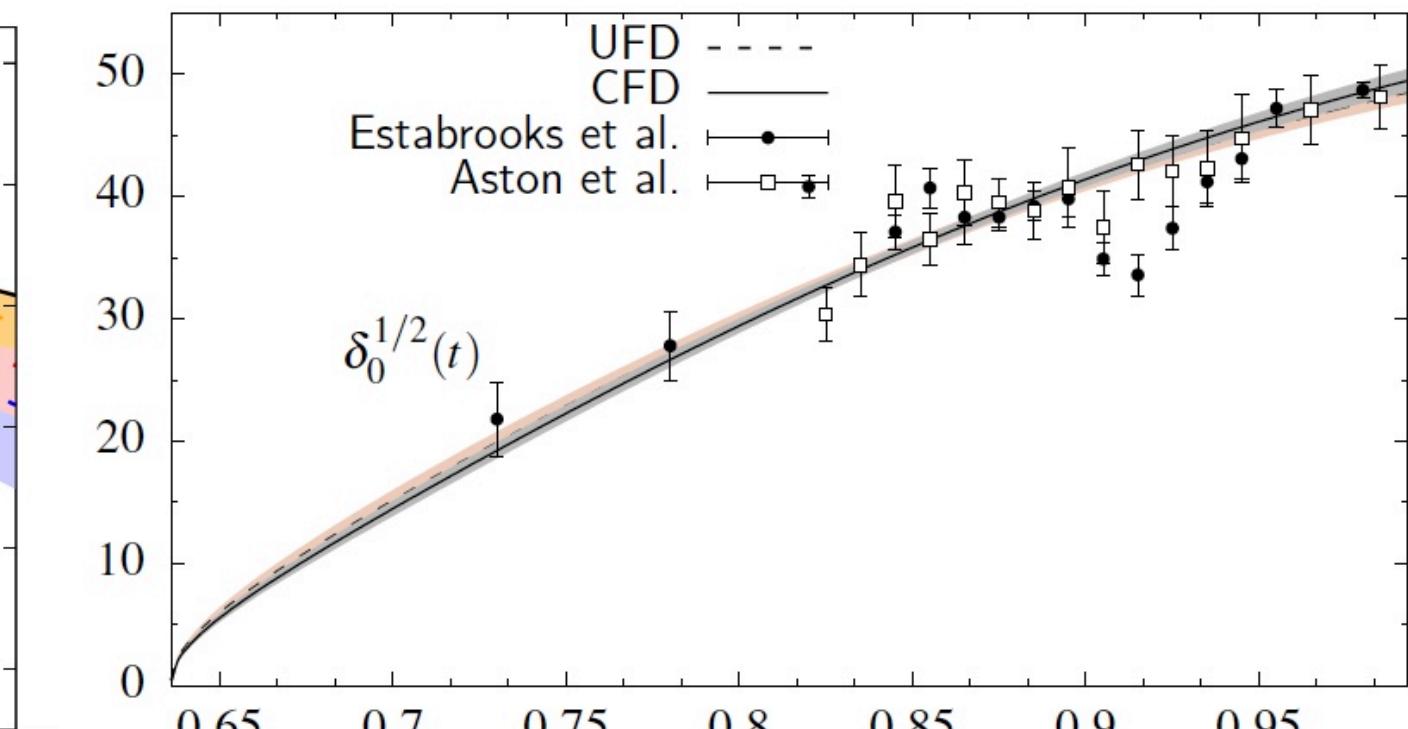
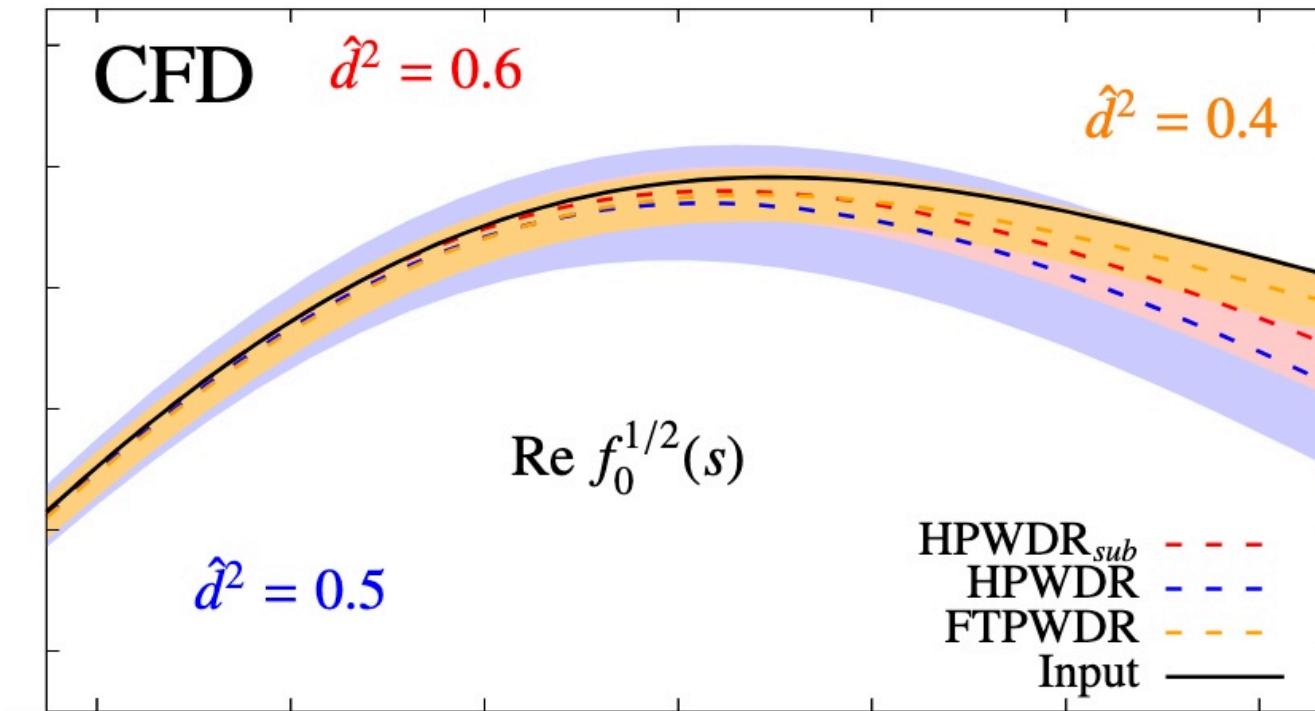
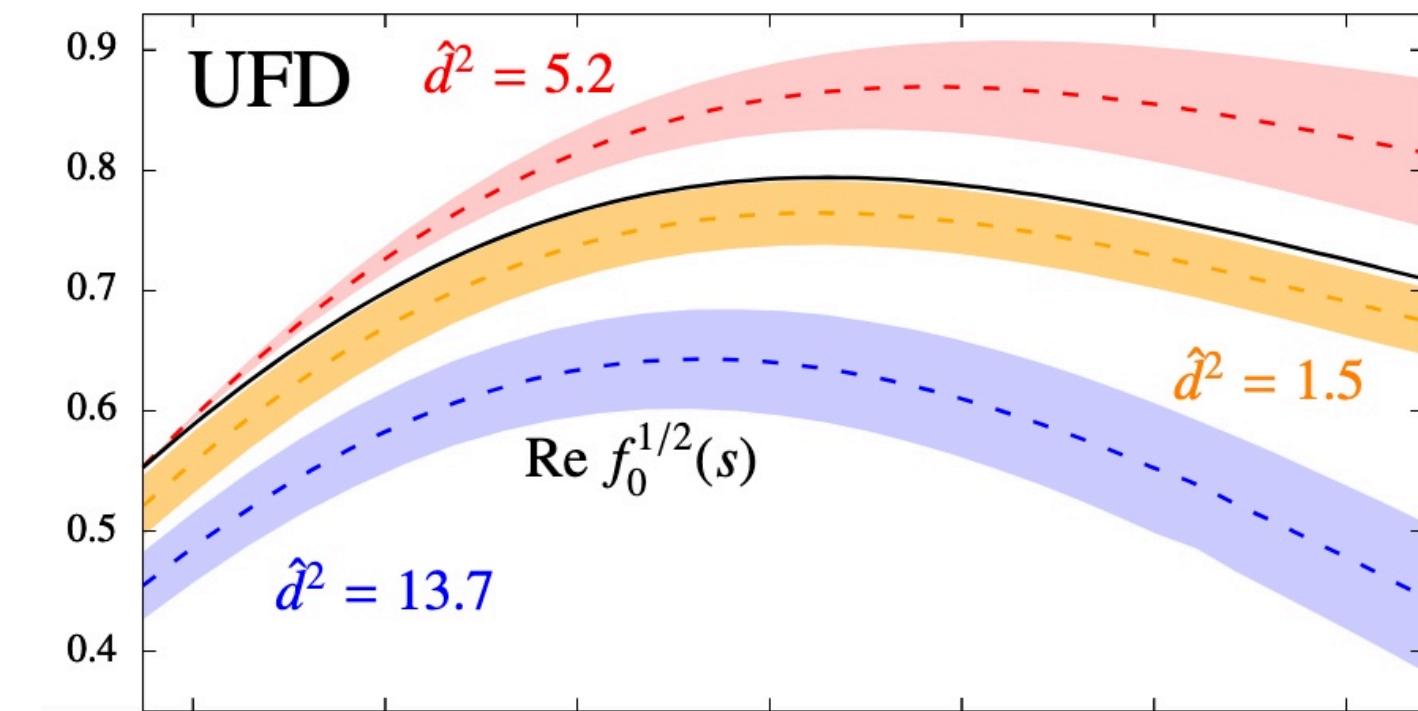
Fit → In

DR → Out

compatible

Vary the fits a bit

$$f_\ell^I(s)$$



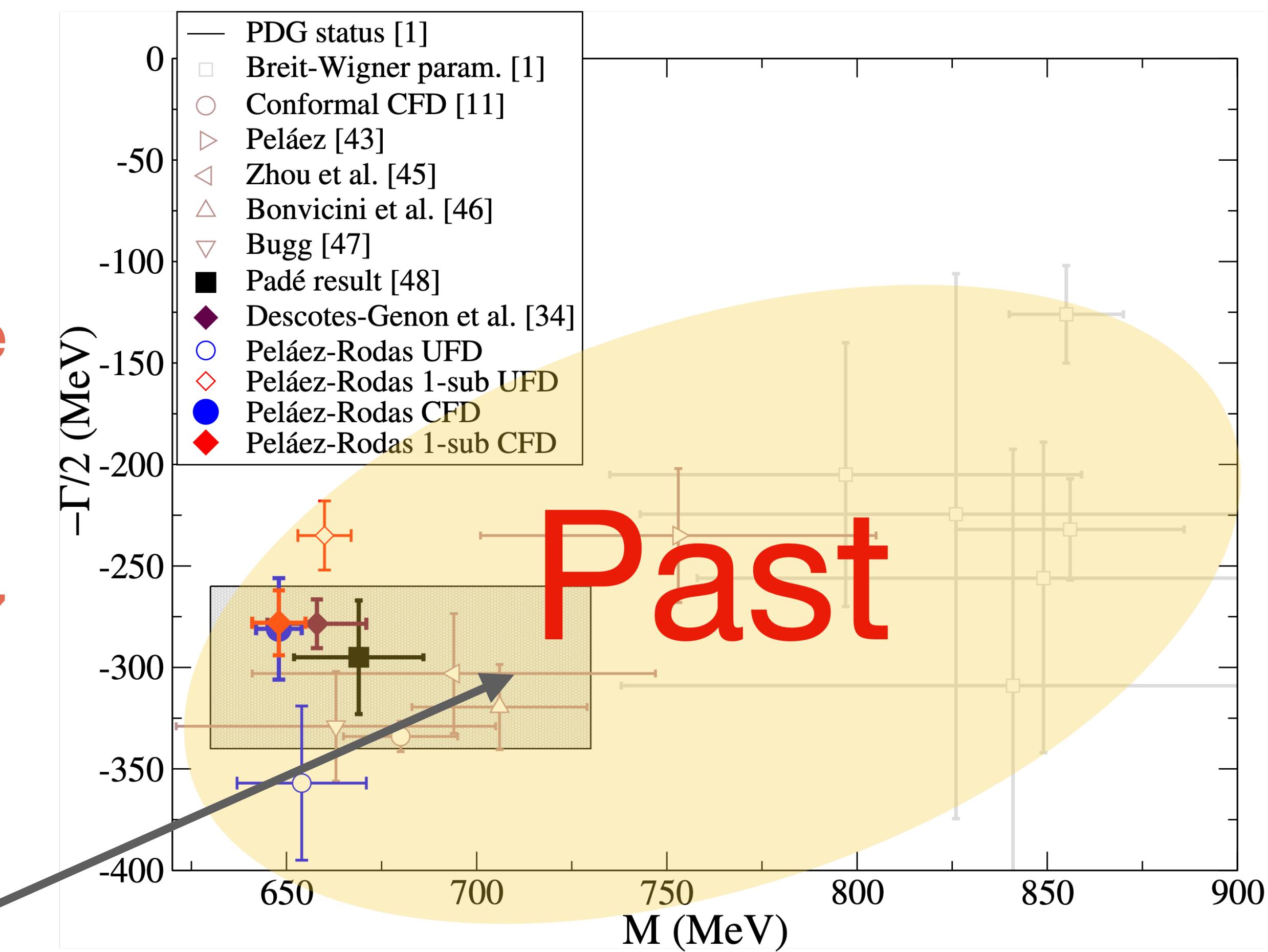
πK scattering

“We are beginning to think that κ should be classified along with flying saucers, the Loch Ness Monster, and the Abominable Snowman”

PDG 1967

Data

$$f_\ell^I(s)$$



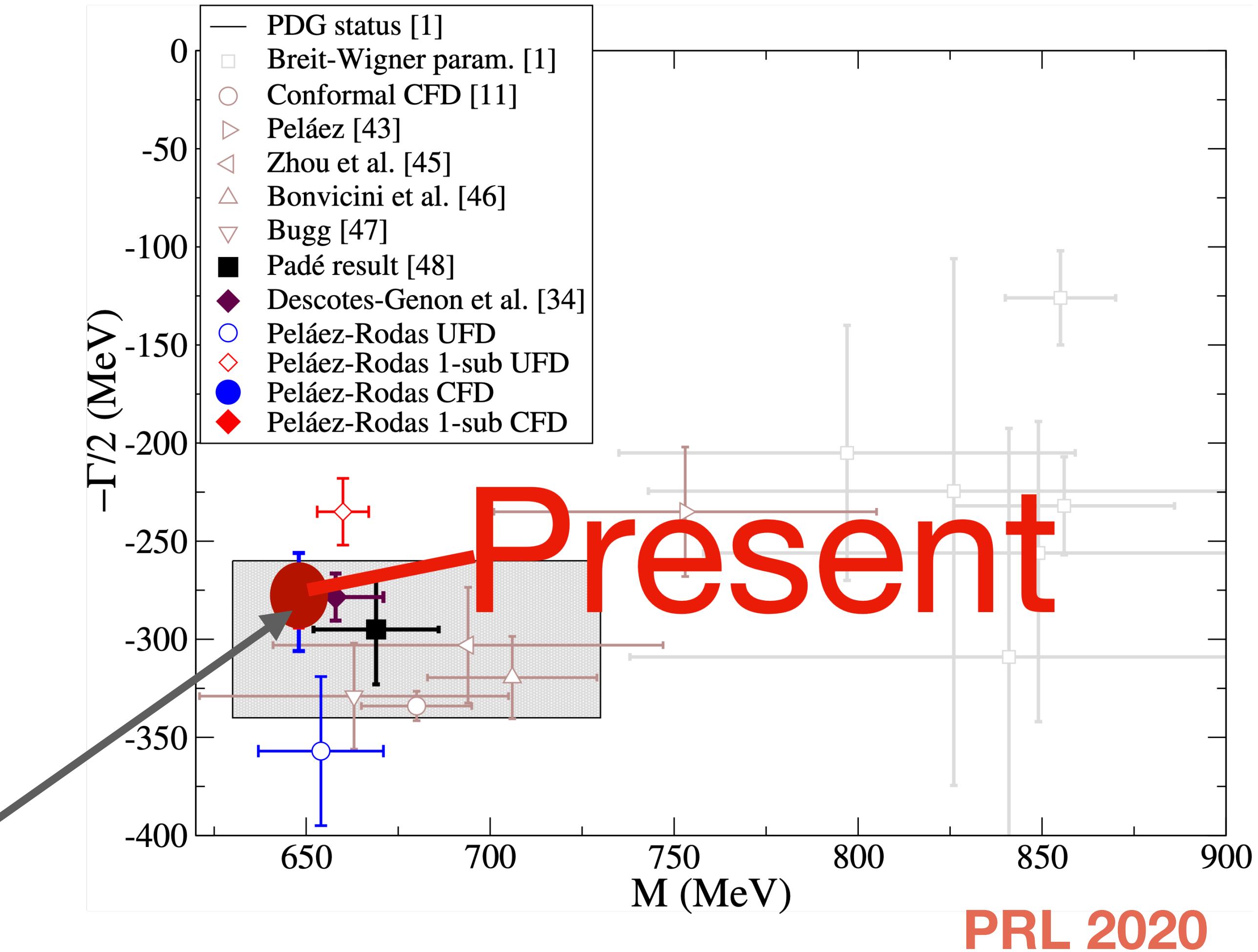
πK scattering

“ κ accepted”

PDG 2021

Dispersive

$$f_\ell^I(s)$$

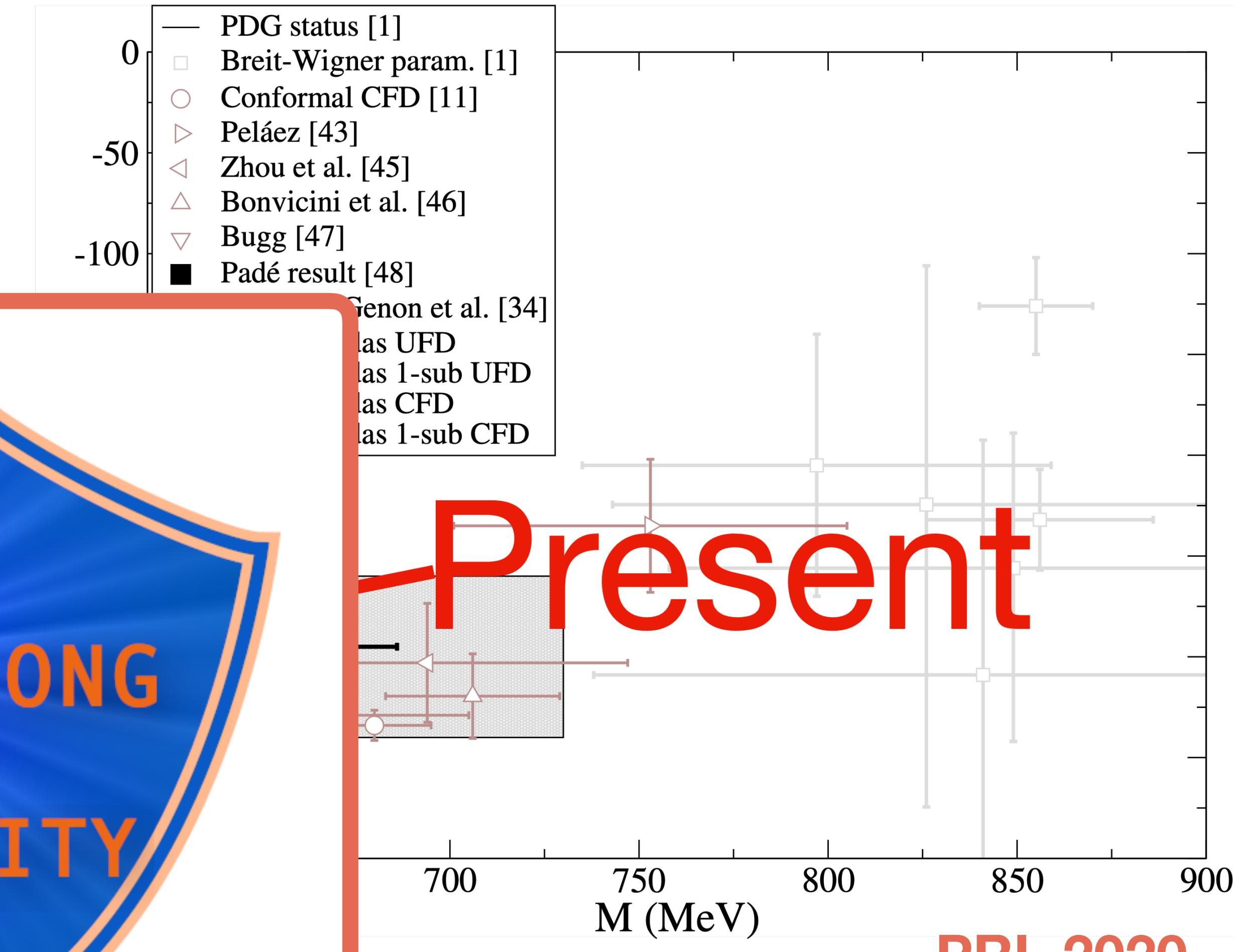


We need “good” data for this

πK scattering

“ κ accepted”

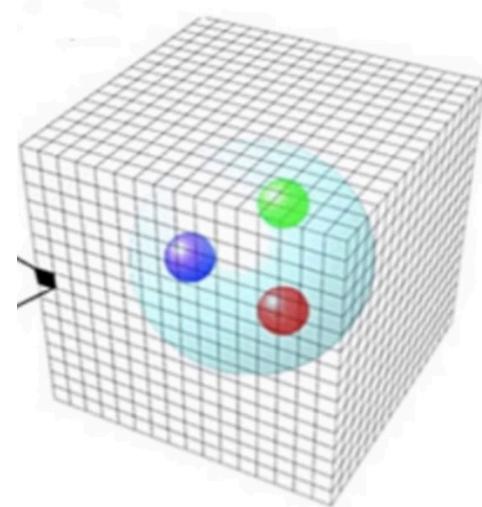
Incoming exp. on
 πK interactions!!



We need “good” data for this

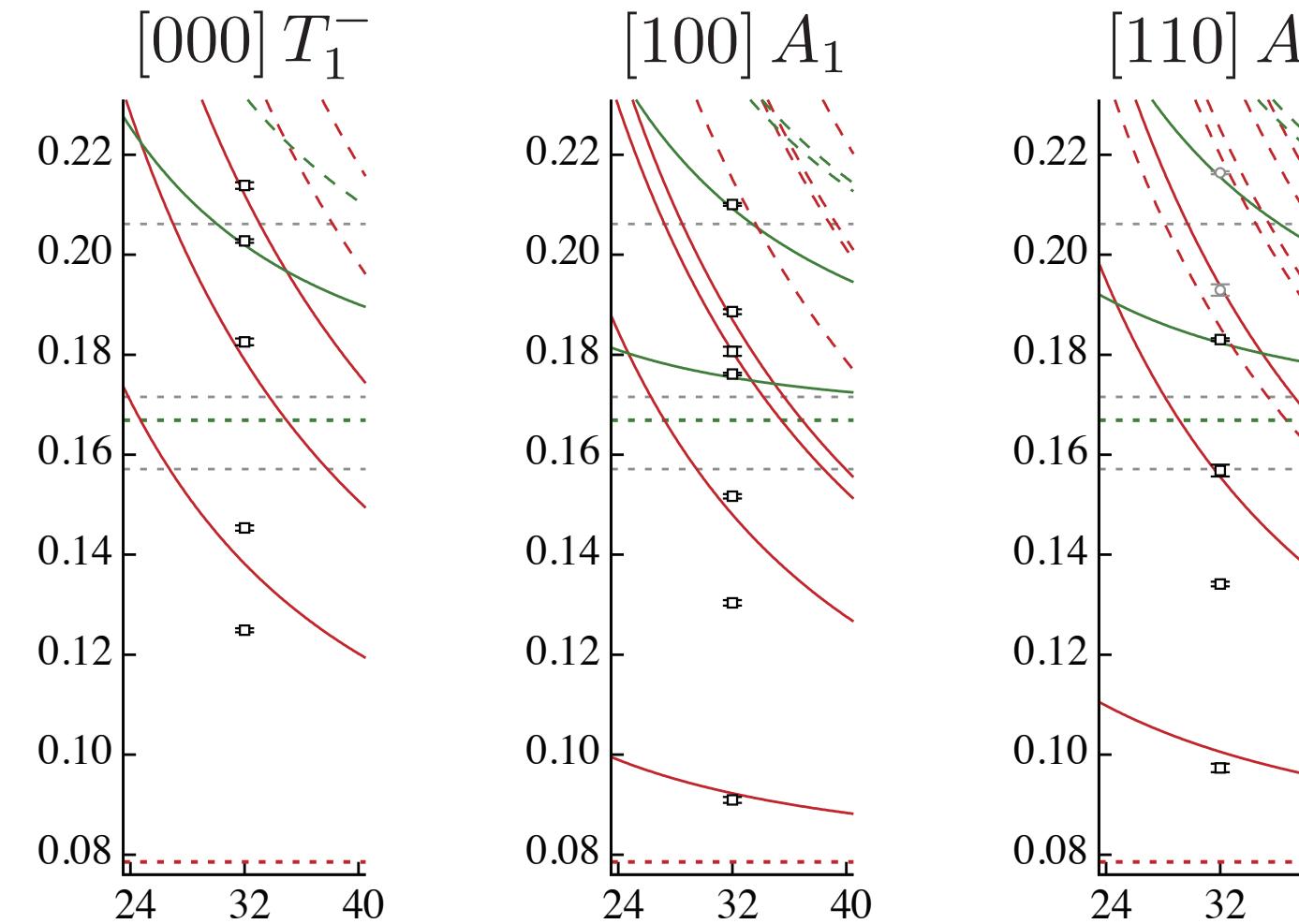
$\pi\pi$ scattering on the lattice

Jo's talk



$$t \rightarrow -it$$

$$-iS = -i \int d^3x dt \mathcal{L} \rightarrow - \int d^3x dt \mathcal{L}_E = -S_E$$

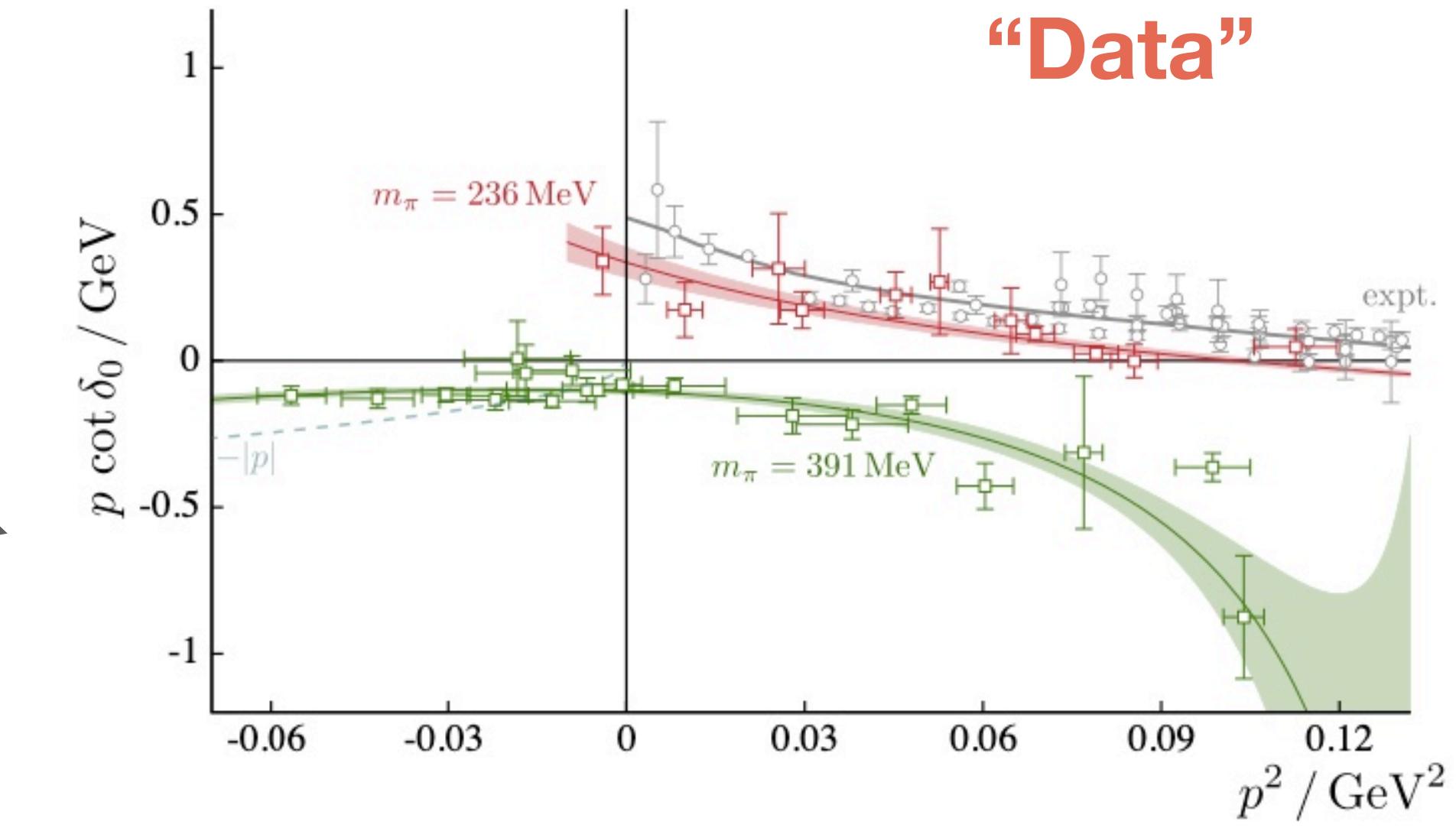


Lüscher

Short future

First lattice QCD+DR

Quantized levels in a box

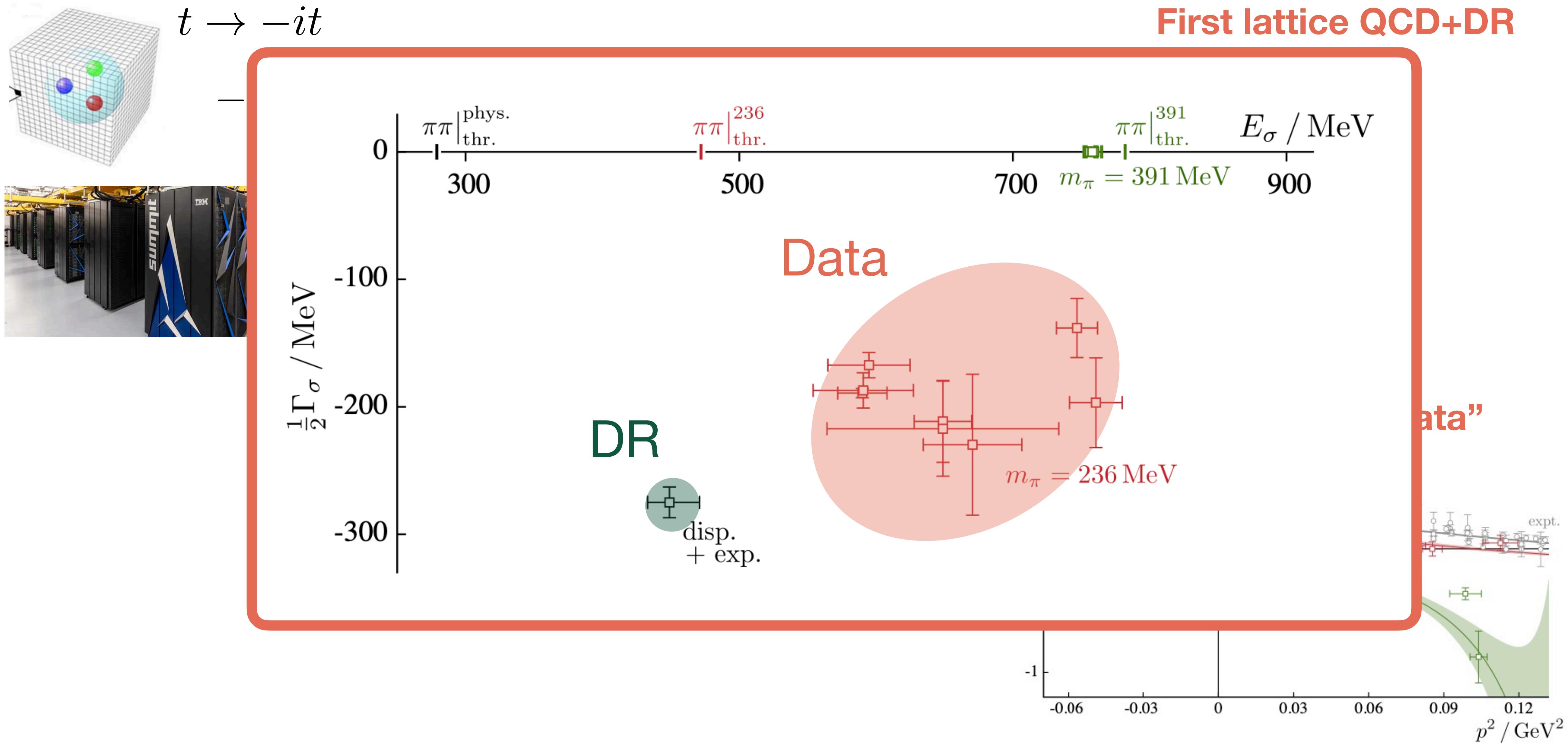


$\pi\pi$ scattering on the lattice

Jo's talk

Short future

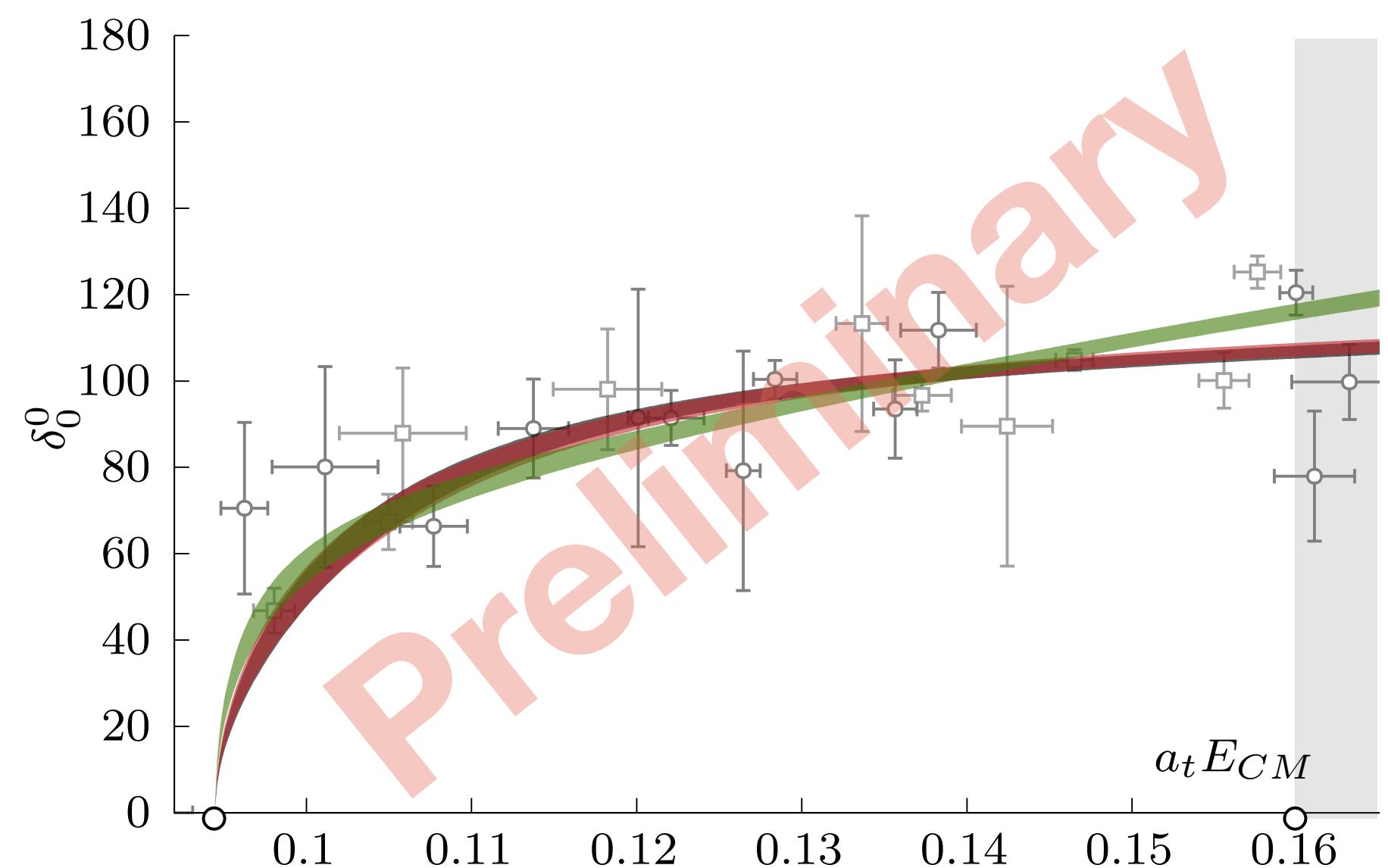
First lattice QCD+DR



$\pi\pi$ scattering on the lattice

Short future

First lattice QCD+DR

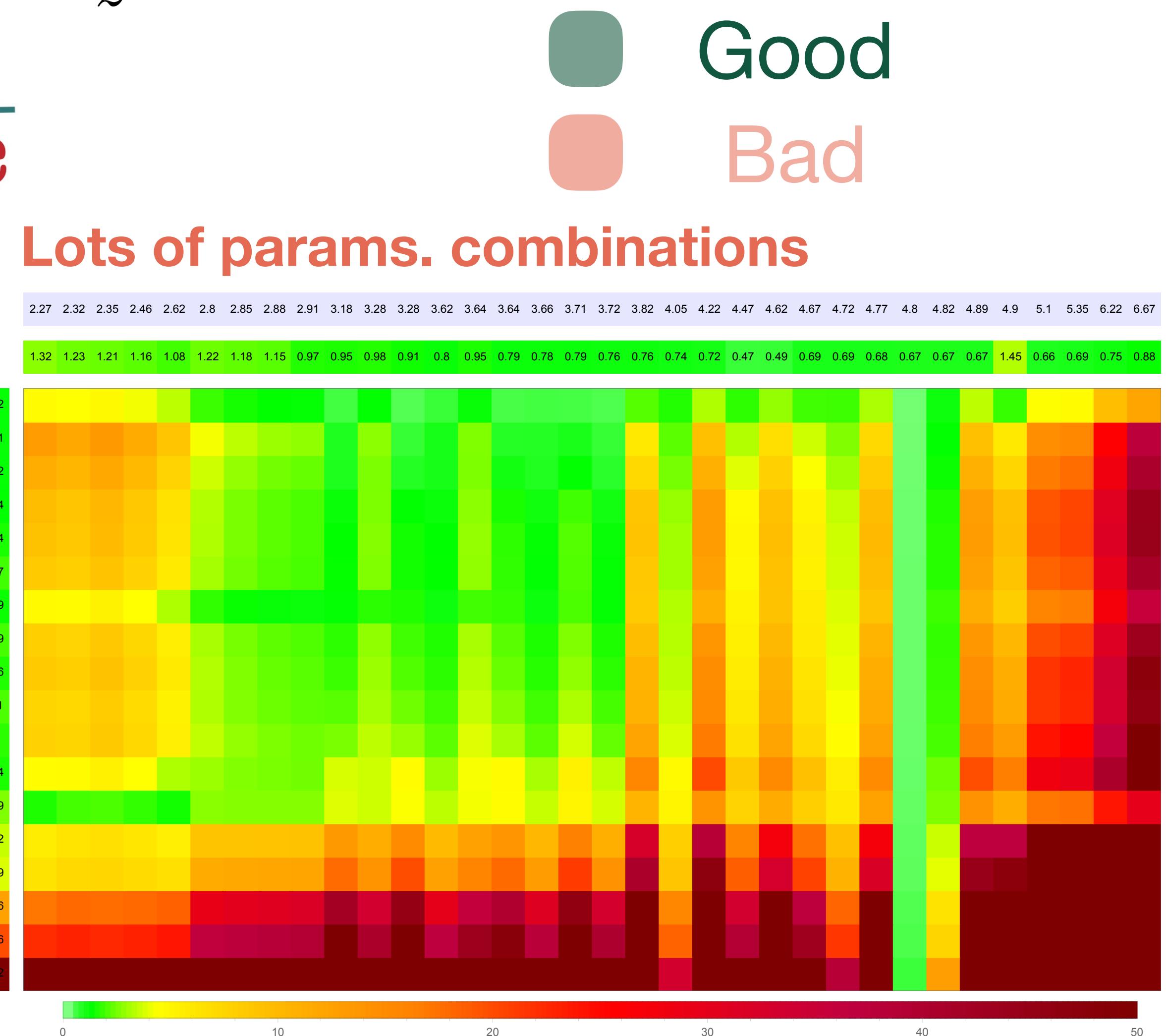


$$t(z) = \oint_C \frac{t(z')}{z' - z} dz'$$

had spec

Not all params.
are created equal

Path to a full theoretical,
first-principles result



Understanding the QCD spectrum

Present



Determine the spectrum



Exp./Lattice



First principles

Understanding the QCD spectrum

Present



Determine the spectrum



Exp./Lattice



First principles

Masses

Lifetimes

Couplings

Future



What are they made of?

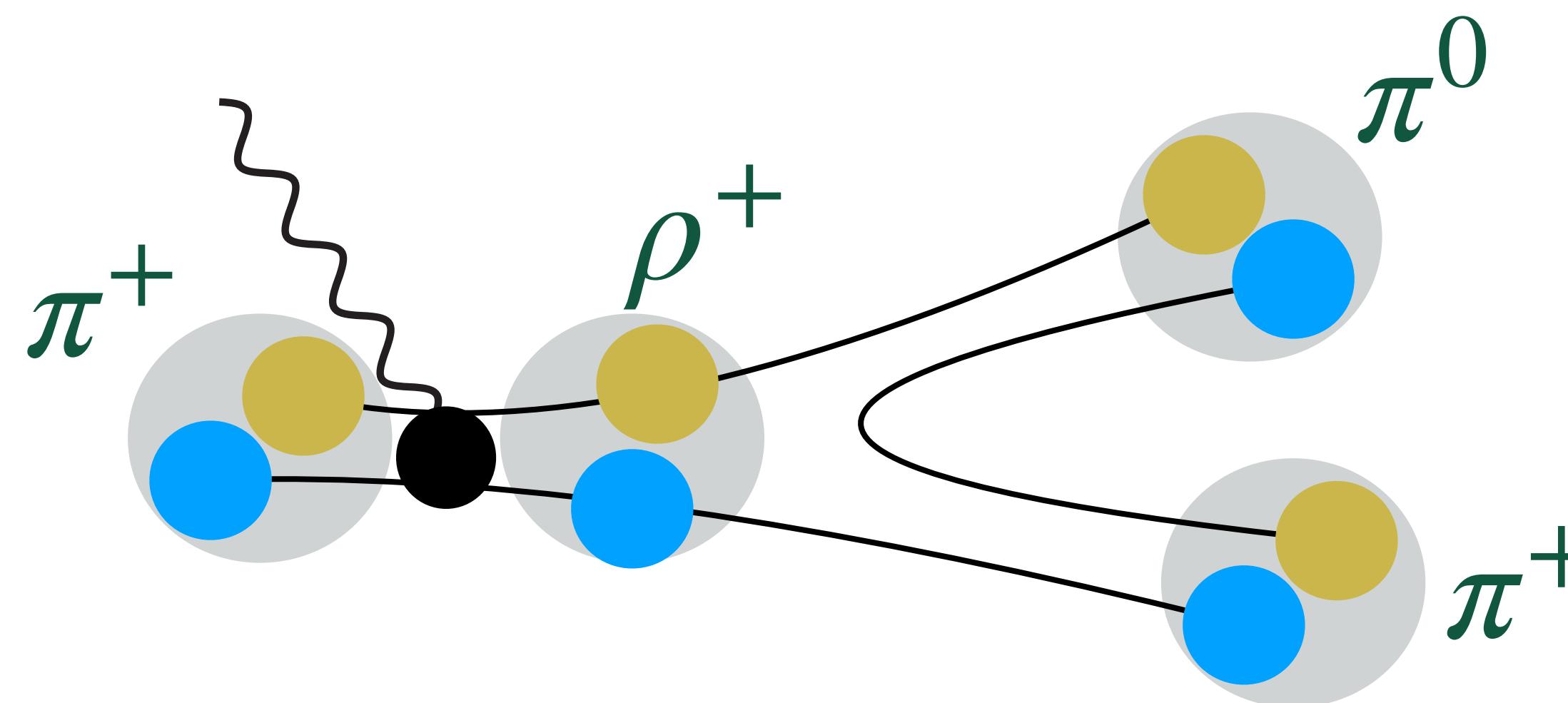
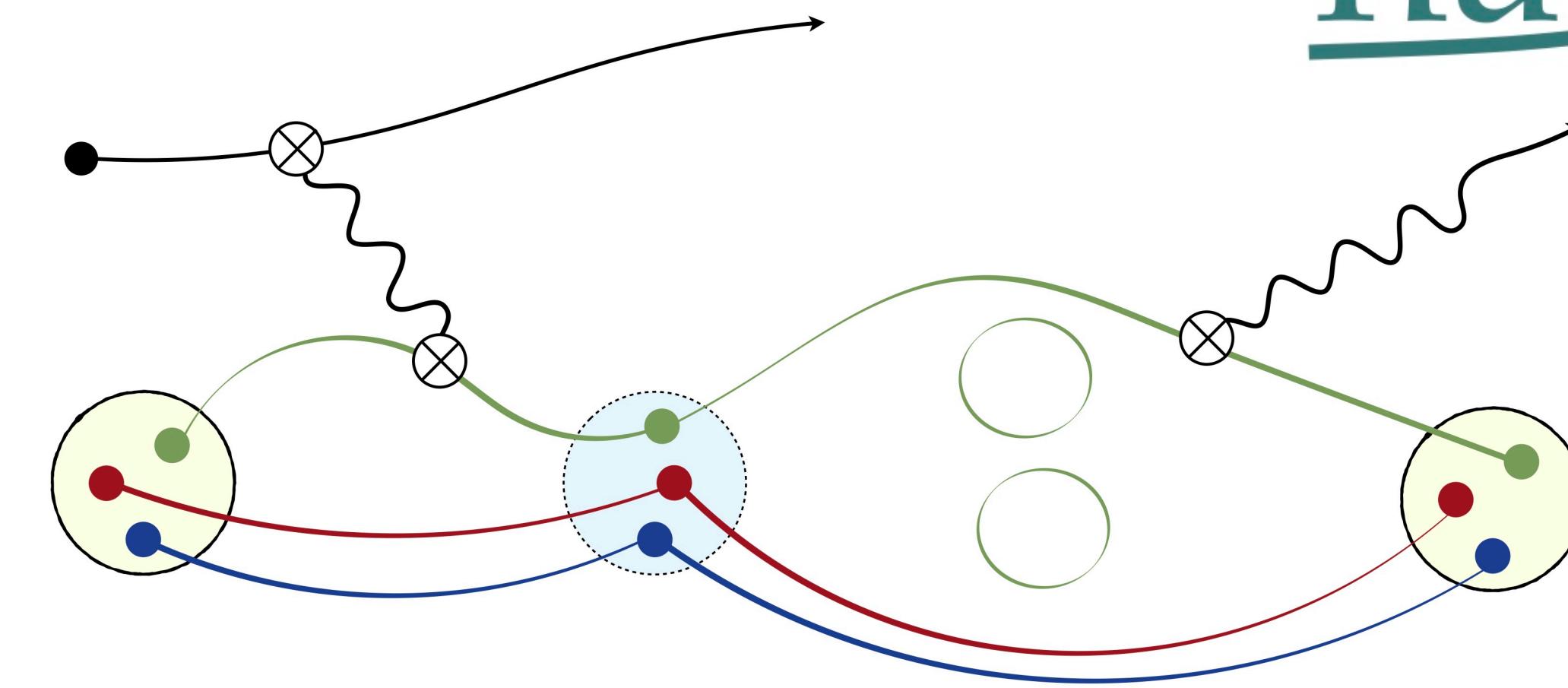


Compositeness

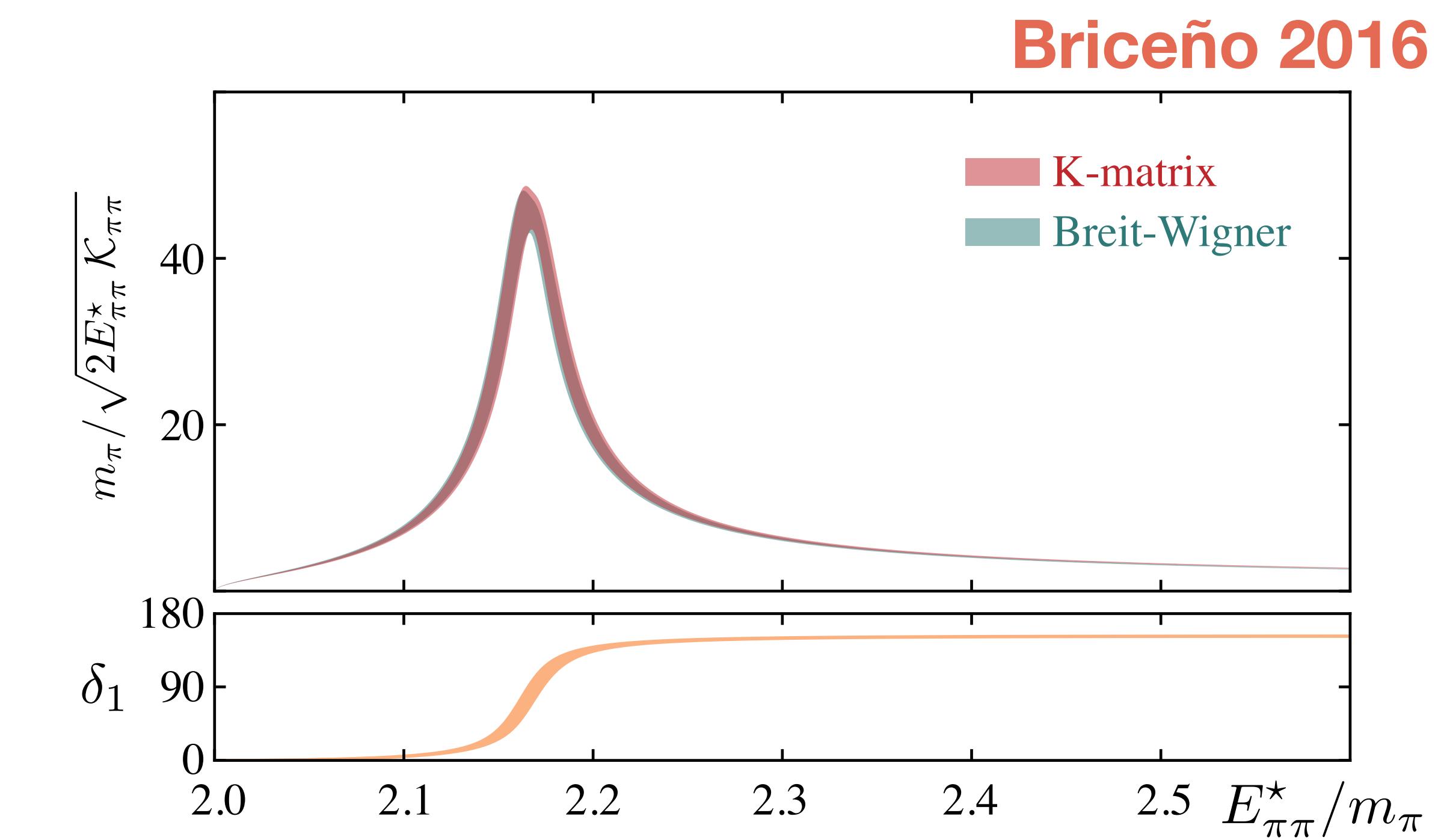
had spec

What's inside?

γ to shed
some light



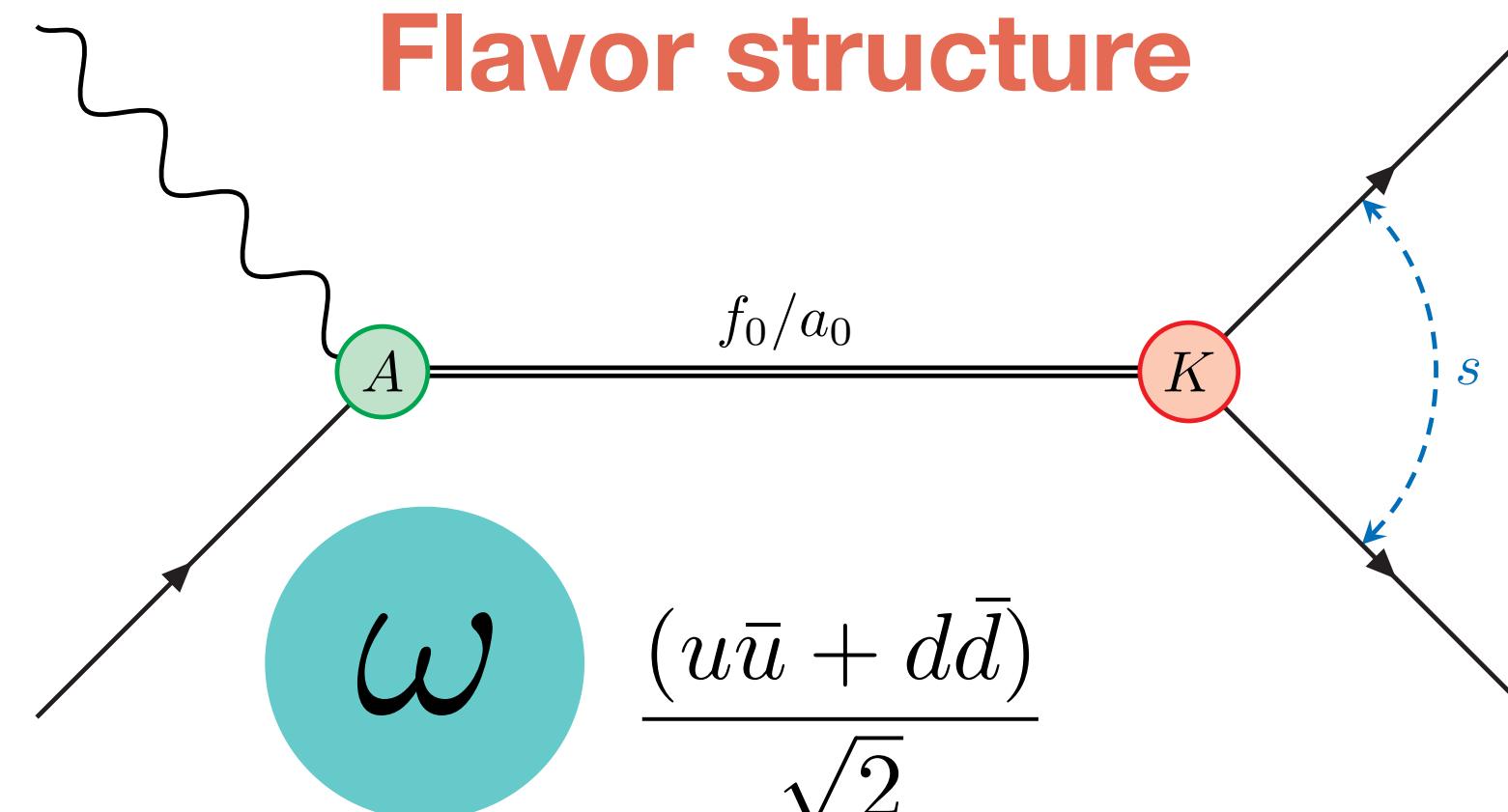
Successful first analyses



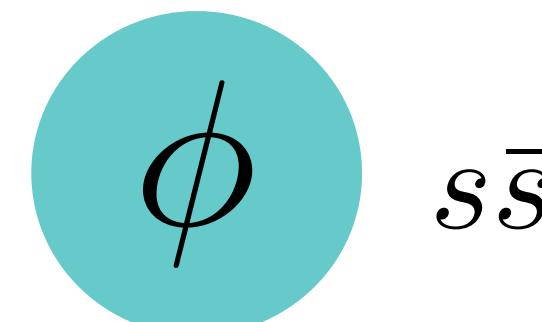
Compositeness

More complicated

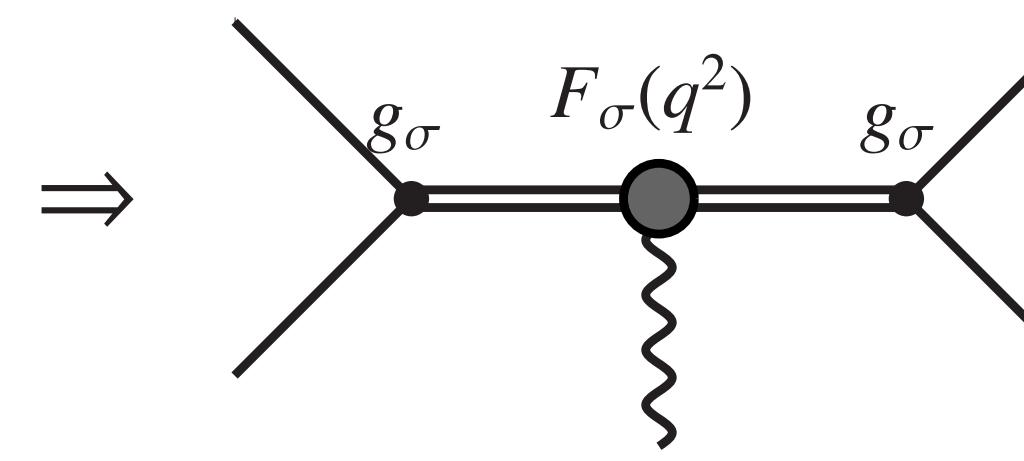
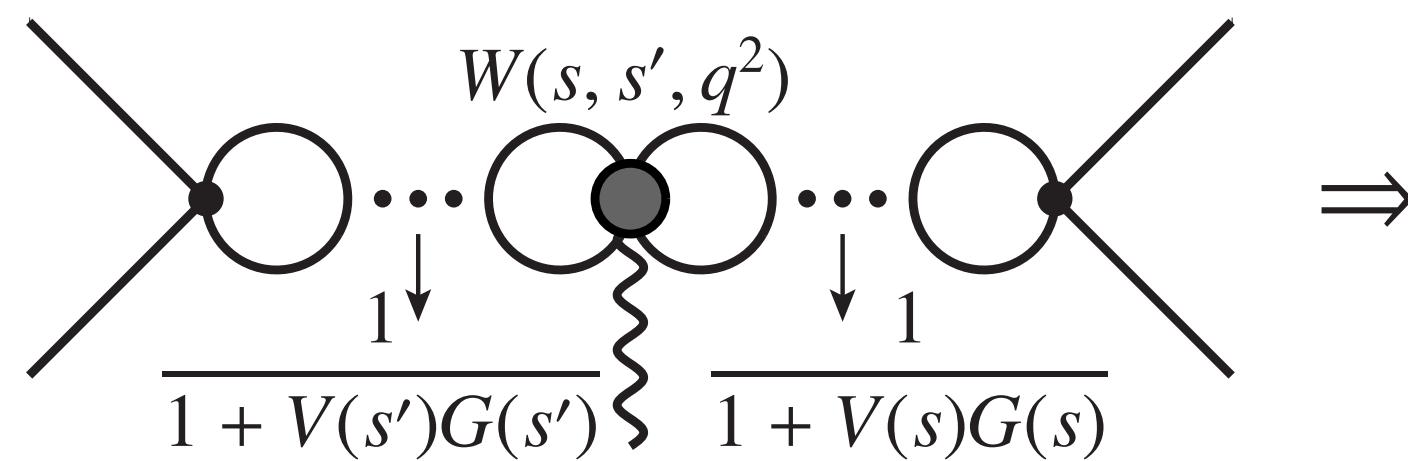
had spec



Remember these?



Resonance structure?



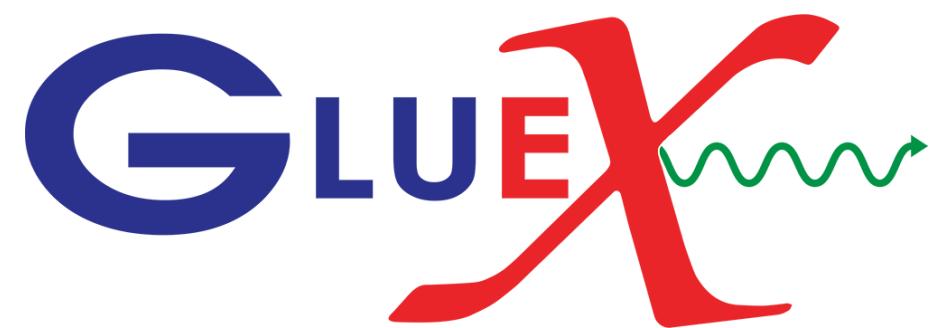
$\gamma \rightarrow$ charge radius
 $h \rightarrow$ mass radius??

First principles

$$t(z) = \oint_C \frac{t(z')}{z' - z} dz'$$

Summary / Outlook

Exciting time for spectroscopy!!



Exotics

Coupled-channels

Various productions



Amplitude analyses

had spec

Photo-production

Current insertions

Multi-body

