The Quest for Strange resonances at KLF

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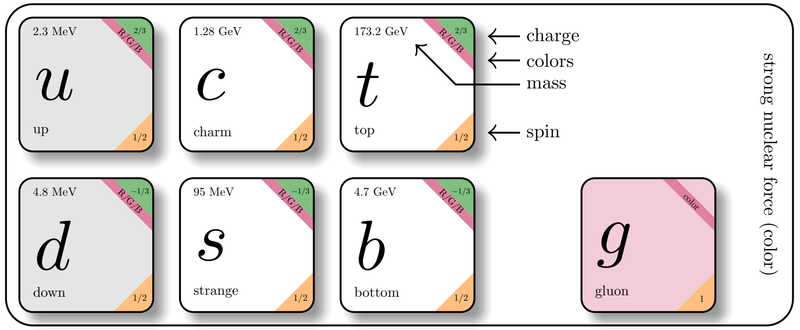
hadspec

ExoHad
Exotic Hadrons Topical Collaboration

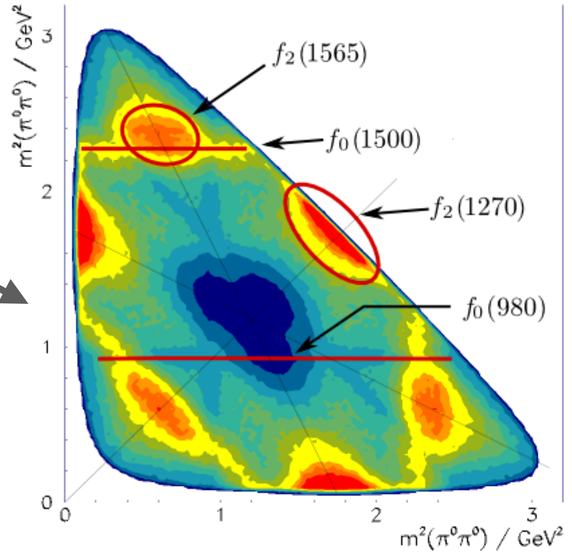
The 2015
LONG RANGE PLAN
for NUCLEAR SCIENCE

"... hadron spectroscopy illuminates the QCD interaction that binds quarks."

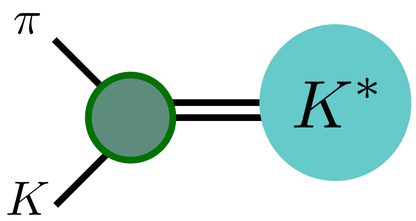
QCD



Understanding



Strange K^* resonances: PDG



The fiercely debated

JRP talk

K*(0)(700)	PDF pdgLive
K*(892)	PDF pdgLive
K*(1410)	PDF pdgLive
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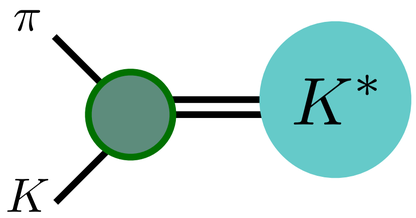
K*(4)(2045)	PDF pdgLive

10 total states

We will stop here

Why can't we go further?

Strange K^* resonances: PDG



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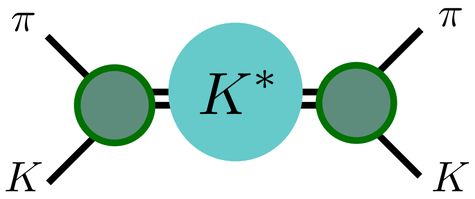

+ Other FSI

K*(0)(700)	PDF pdgLive
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Why can't we go further?

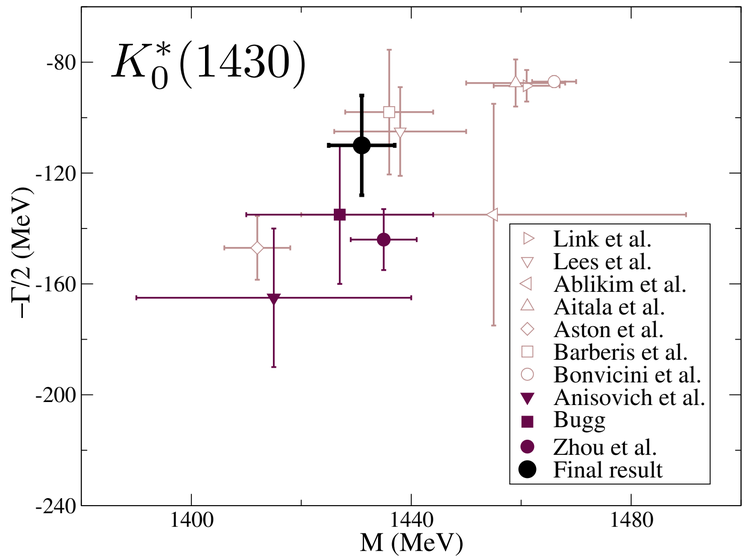
What can we help with?

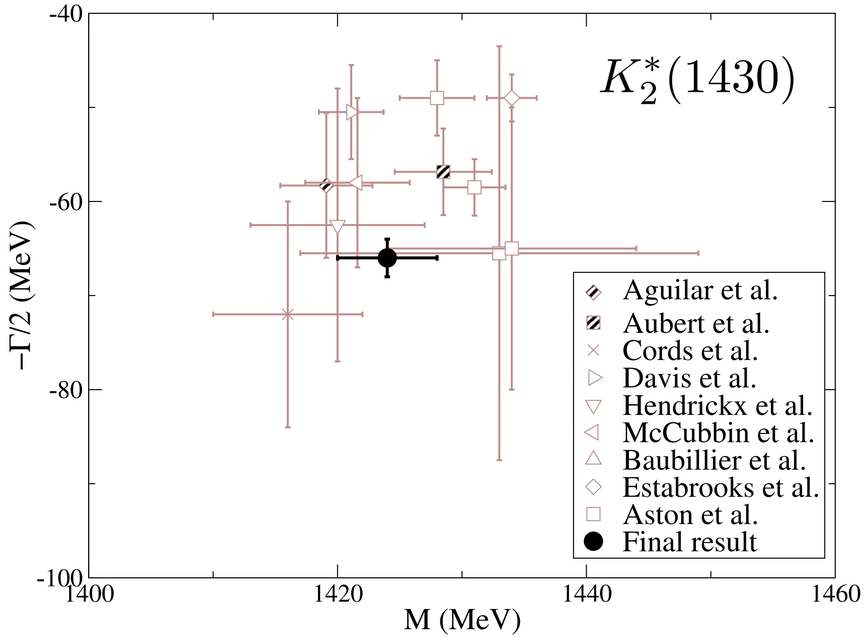
JRP talk

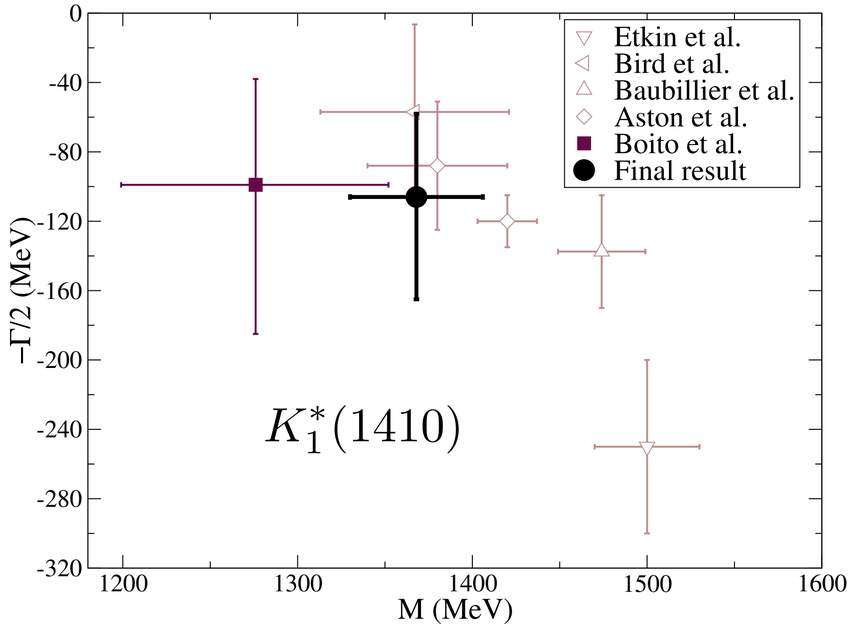
Heavier K^* are poorly known

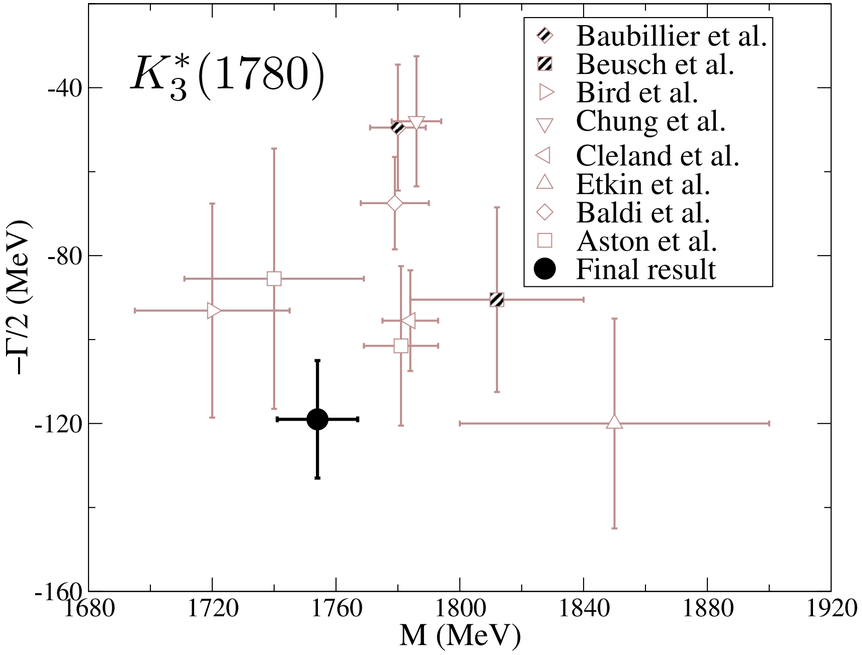
Different production mechanisms lead to not very consistent results

Scattering should provide a clean extraction of these states









What can we help with?

JRP talk

K_0^*

Second lightest resonance

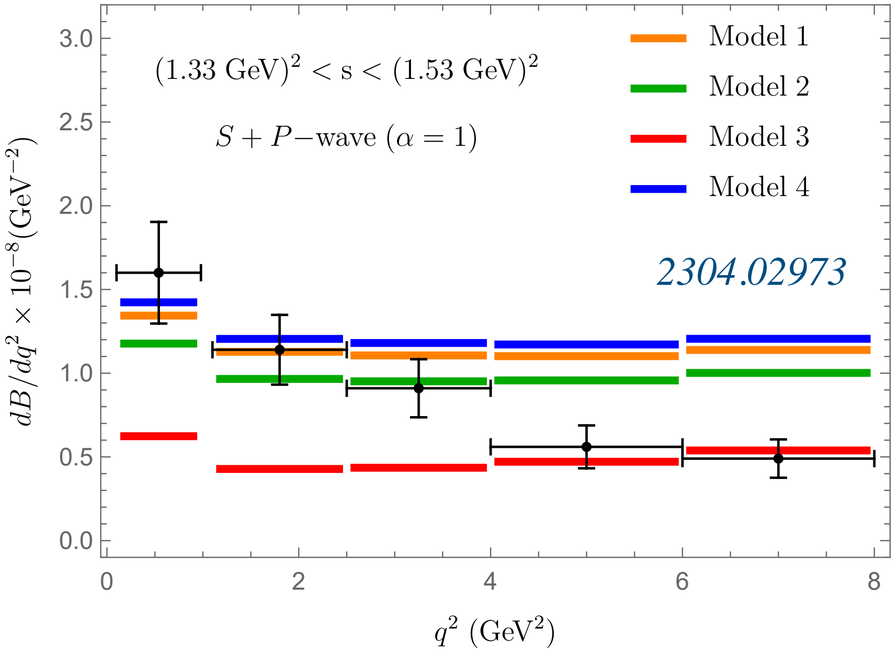
Extremely broad → extremely short-lived

Correlated with chiral symmetry-breaking phenomena

Not well-understood → new observables ??

Input to hadron physics observables

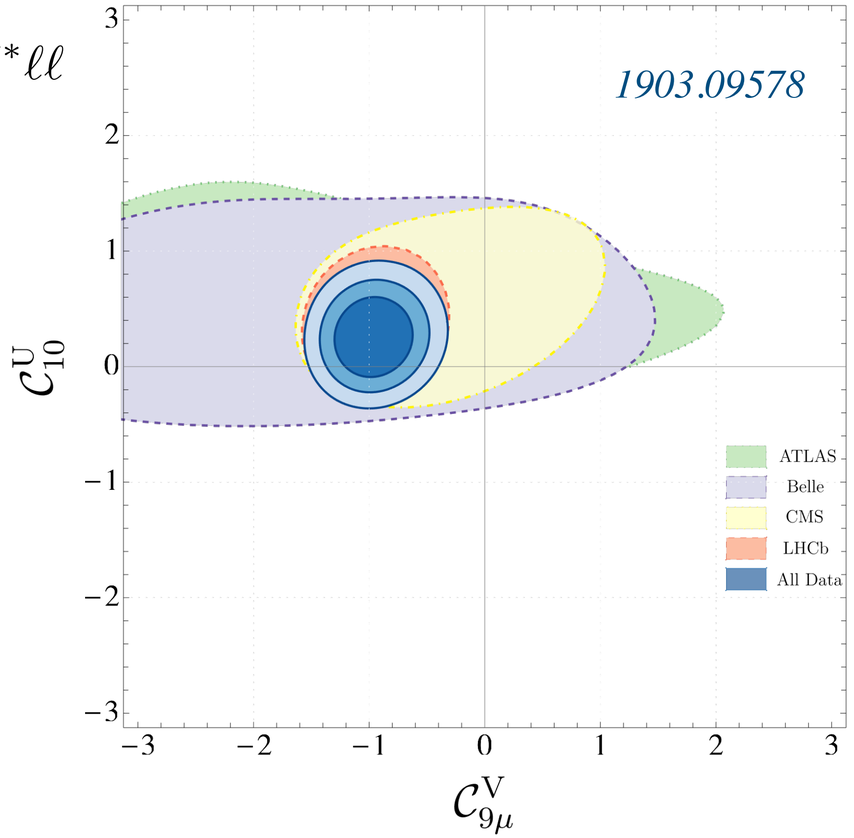
$B \to K\pi$



K^*

K_0^*

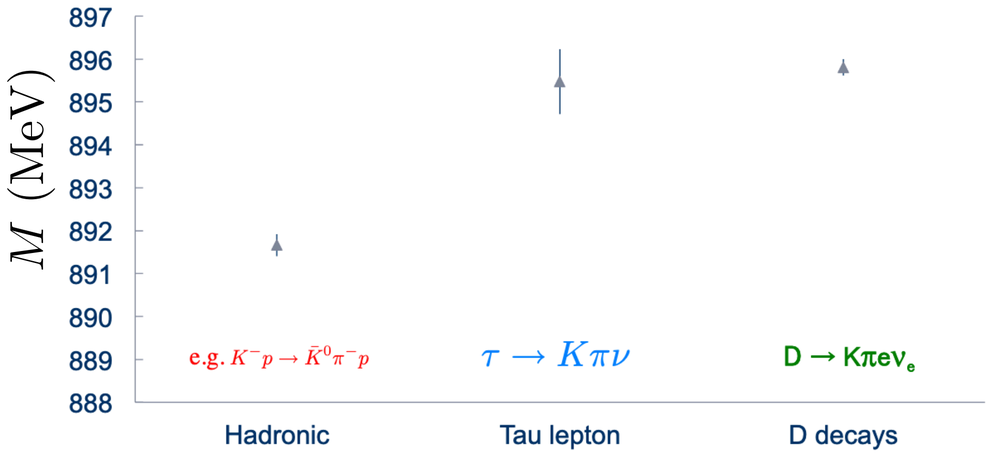
$B \to K^*\ell\ell$

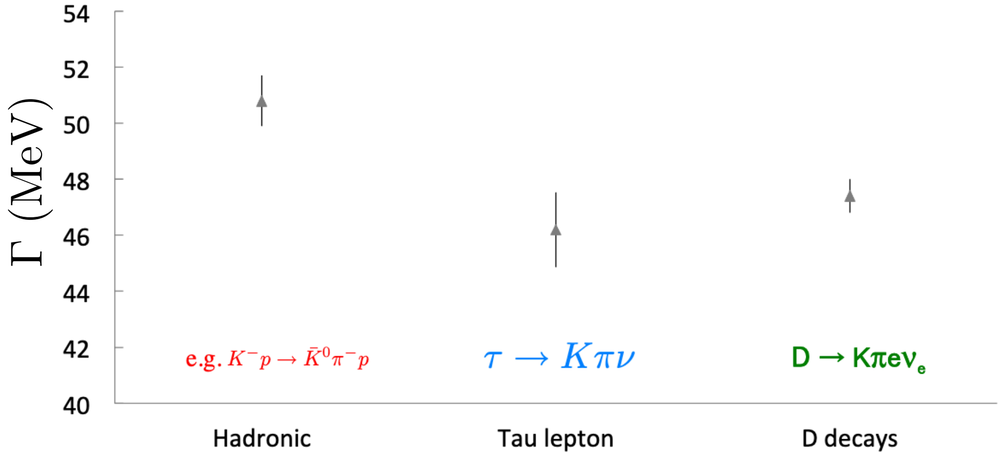


Other applications?

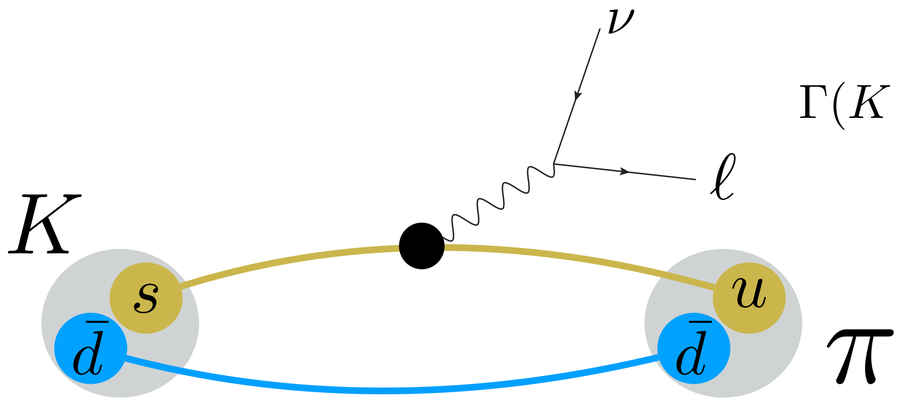
https://wiki.jlab.org/klproject/images/c/cd/EPassemar_SeminarKL.pdf

Not even the narrow $K^*(892)$ is so well known





Flavor determinations and BSM searches often rely on hadronic determinations as input



$$\Gamma(K \to \pi l \nu[\gamma]) = \frac{G_F^2 m_K^5}{192\pi^3} C_K^2 S_E^K |V_{us}|^2 \left| f_+^{K^0\pi^-}(0) \right|^2 I_K^l \left(1 + \delta_{\mathrm{EM}}^{Kl} + \delta_{\mathrm{SU}(2)}^{K\pi}\right)^2$$

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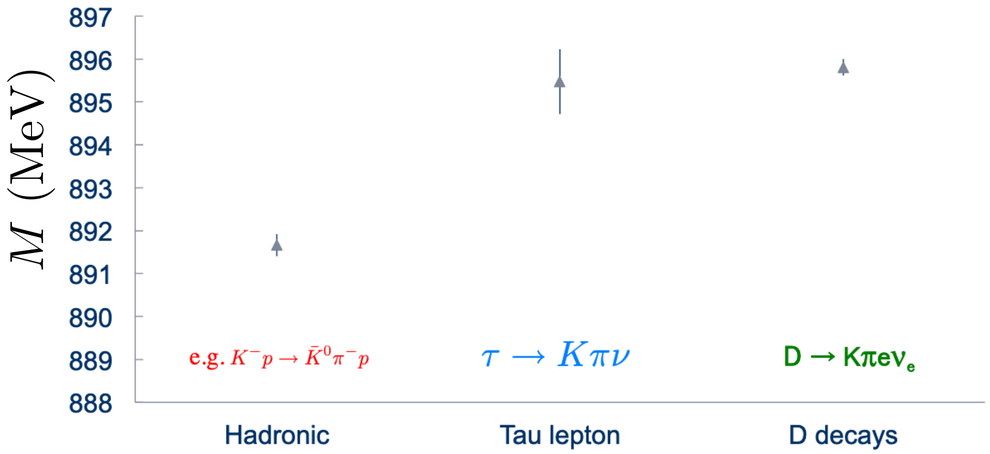

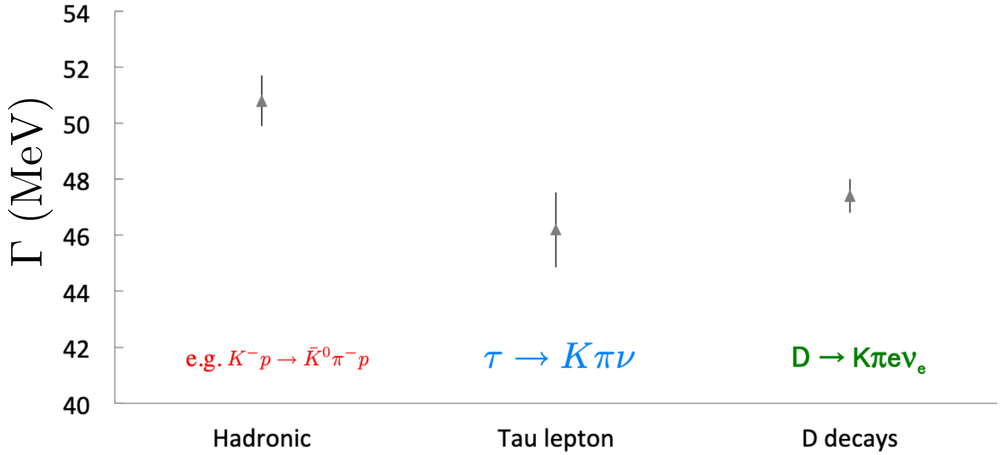

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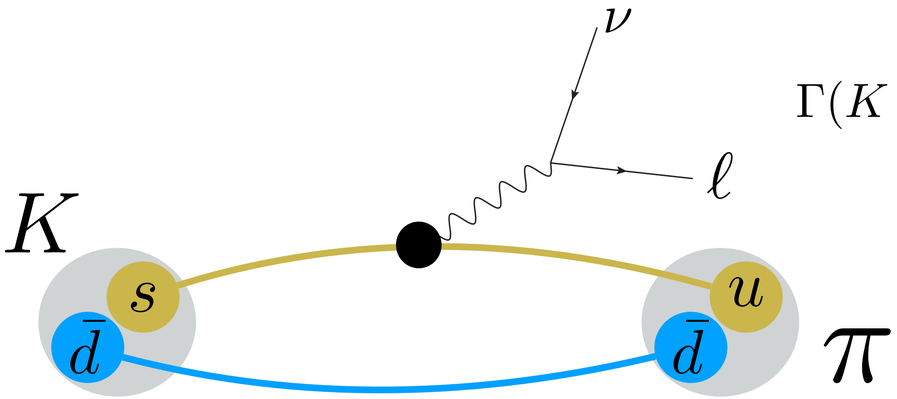

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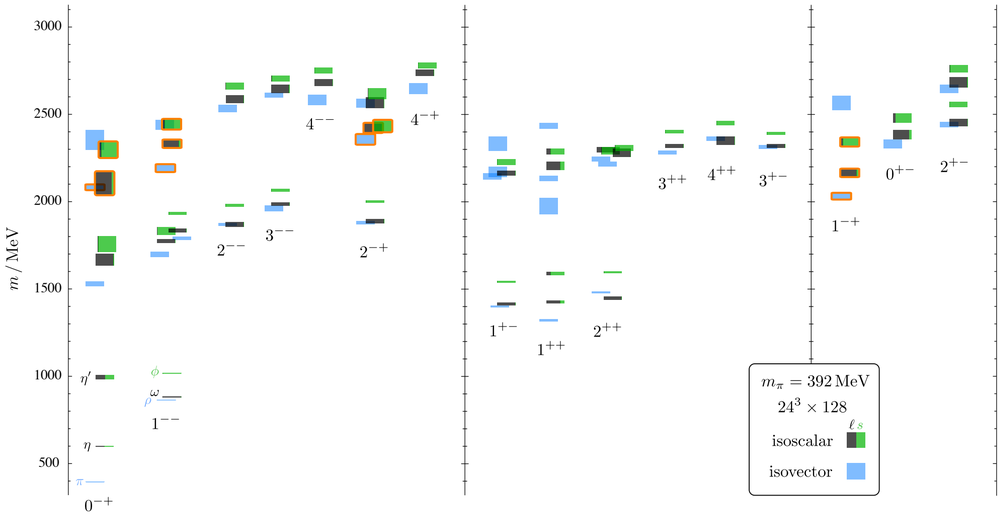
CKM

Vector+Scalar πK form factors

QCD spectrum



Challenge I

Our states are not lines in the spectrum, they decay

How do we model our states adquiring some "width"?

Challenge II

How do we measure these decaying states?

Is there a basic "go to" experiment?

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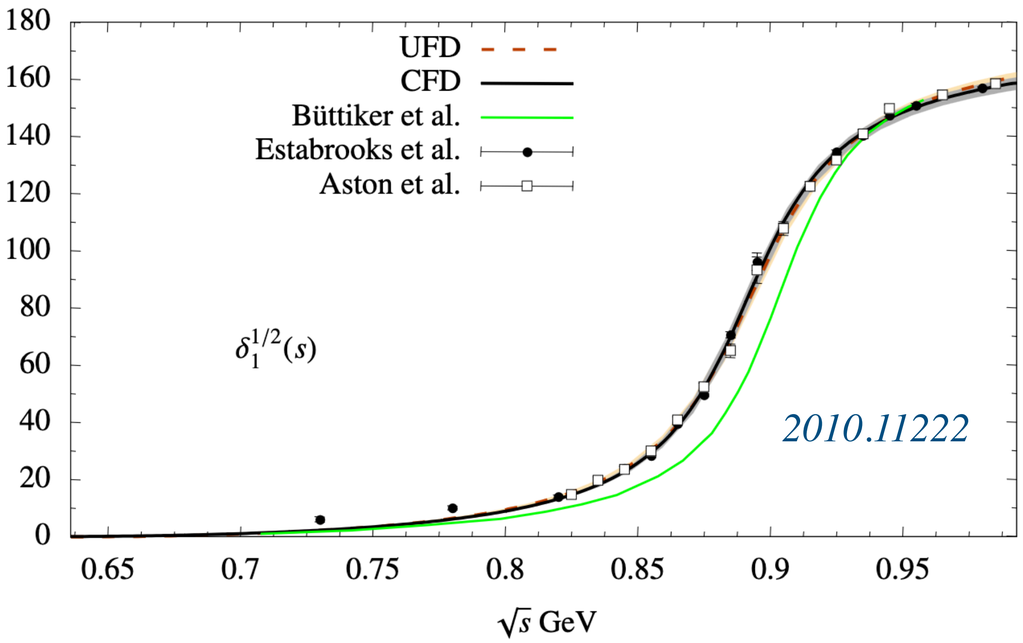
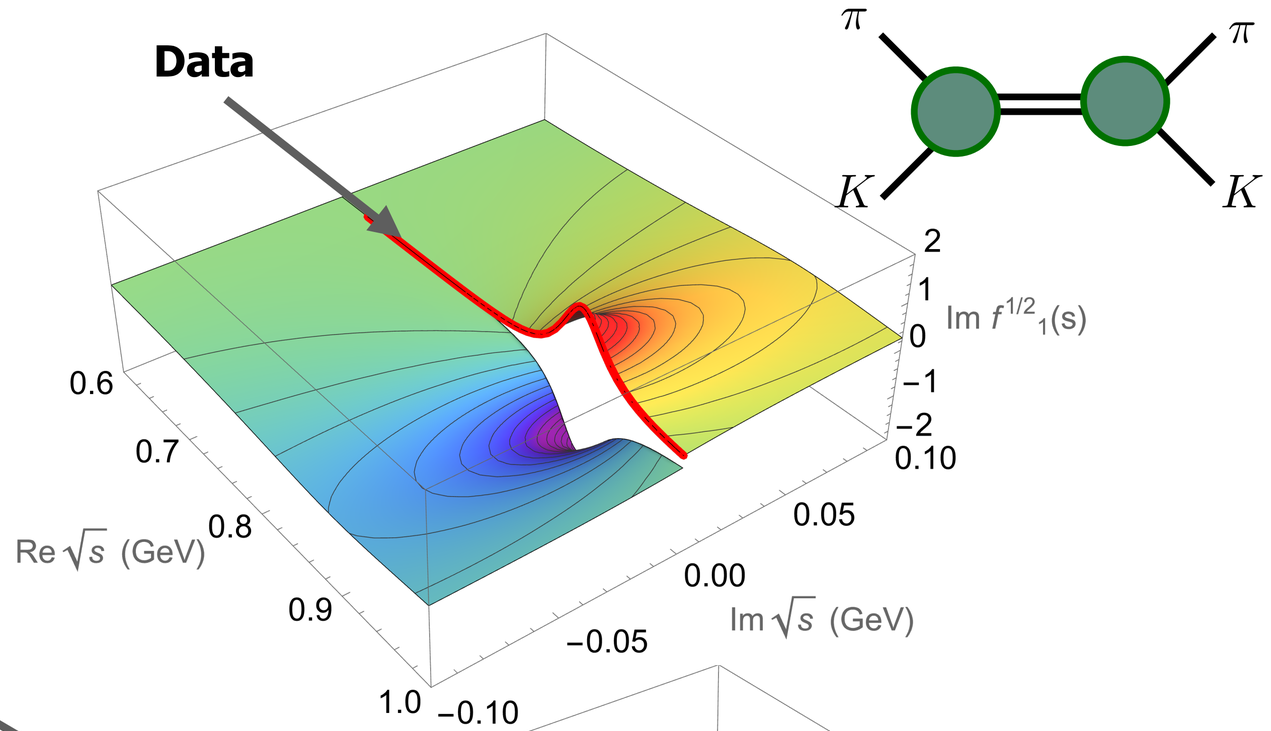
Challenge I

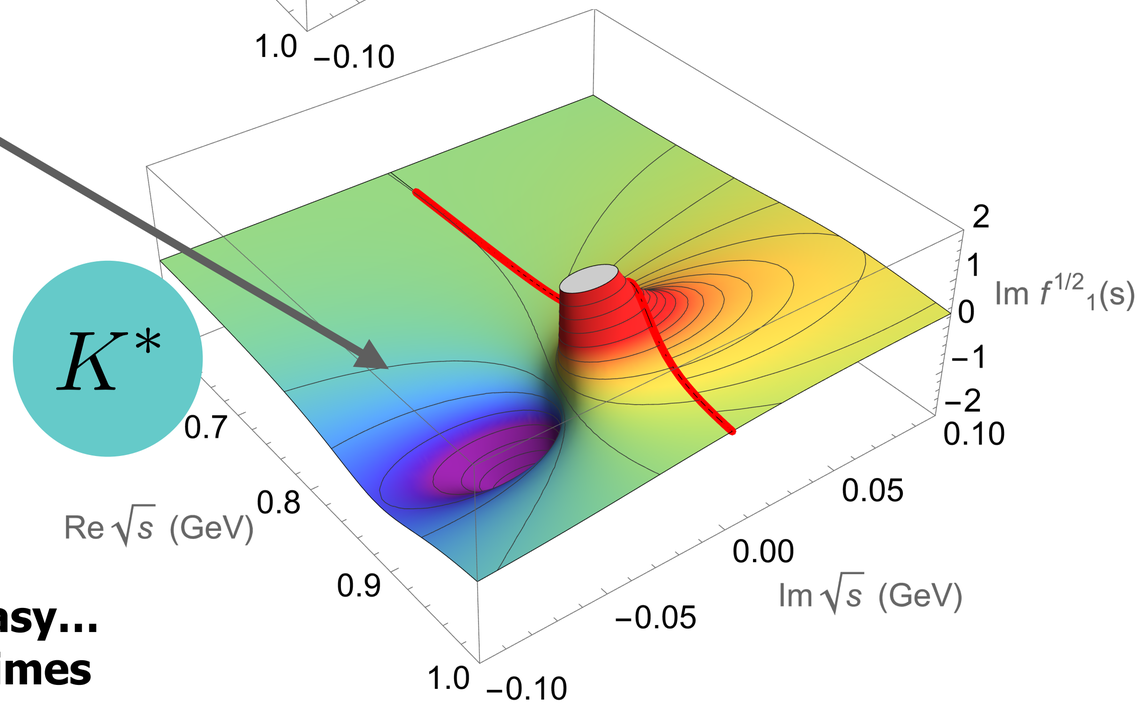
The BW has worked wonders in many cases

$$t_\ell(s) \sim \frac{\sqrt{s}\Gamma(s)}{m^2 - s - i\sqrt{s}\Gamma(s)}$$

$$\sqrt{s_p} = m + i\Gamma/2$$







Life is easy… sometimes

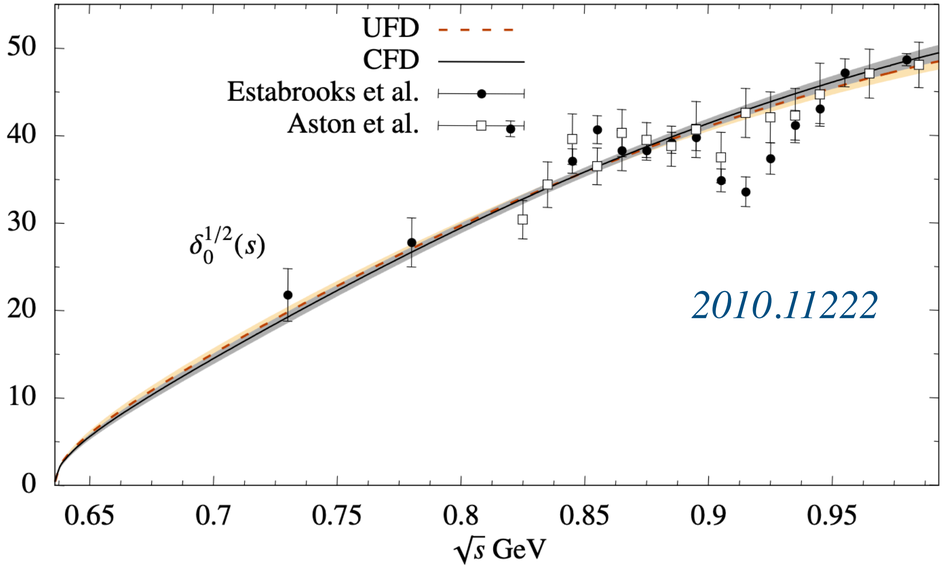
Scattering

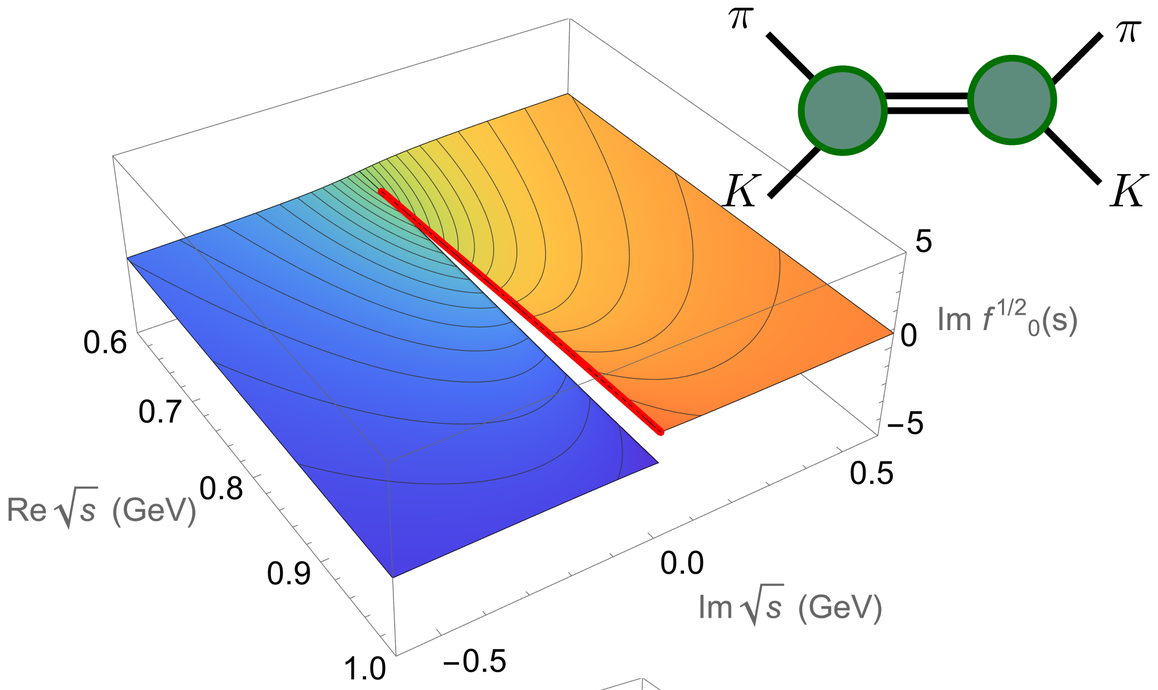
Definitely not a BW

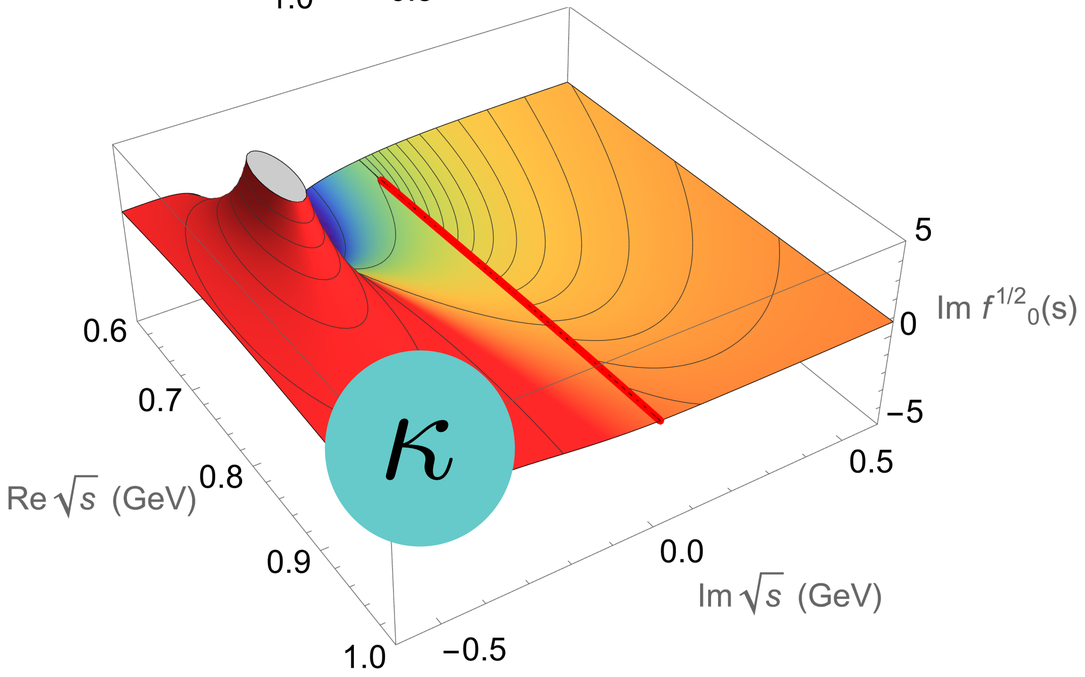
$$t_\ell(s) \sim ??$$

JRP talk

What's this??

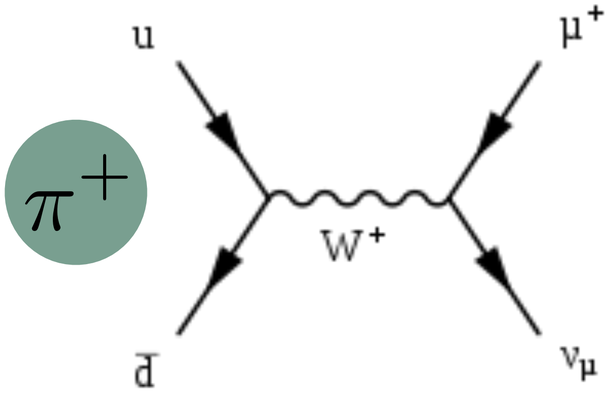






Challenge II

$c\tau_{\pi^+} = 7.8\ \mathrm{m}$

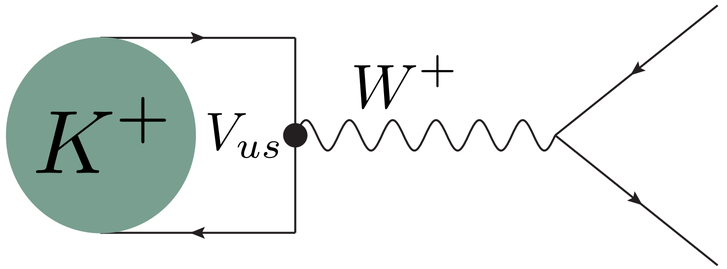


Mesons decay

One beam?? (maybe)

Not two beams

$c\tau_K = 3.7\ \mathrm{m}$



“Data” is not data

For meson-meson data must be always modeled

Some systematic uncertainties unknown

Challenge II

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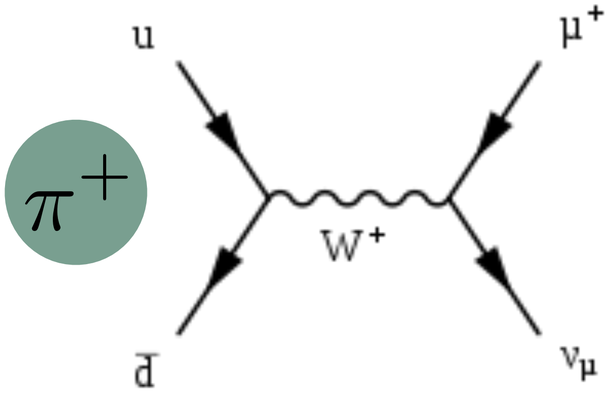

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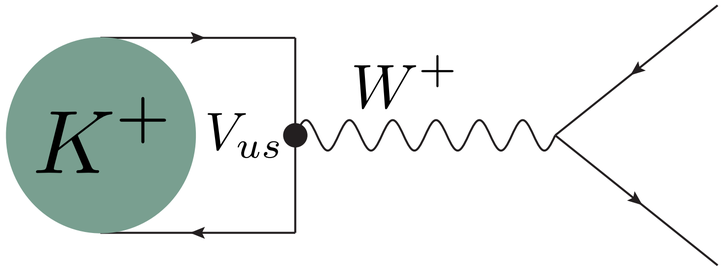

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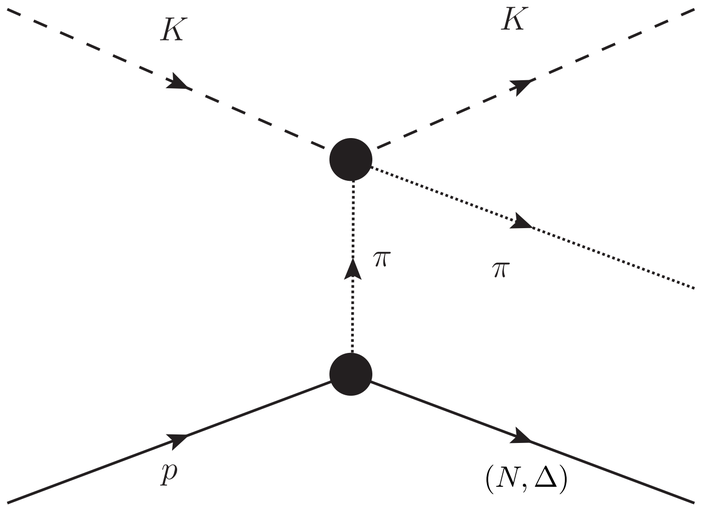
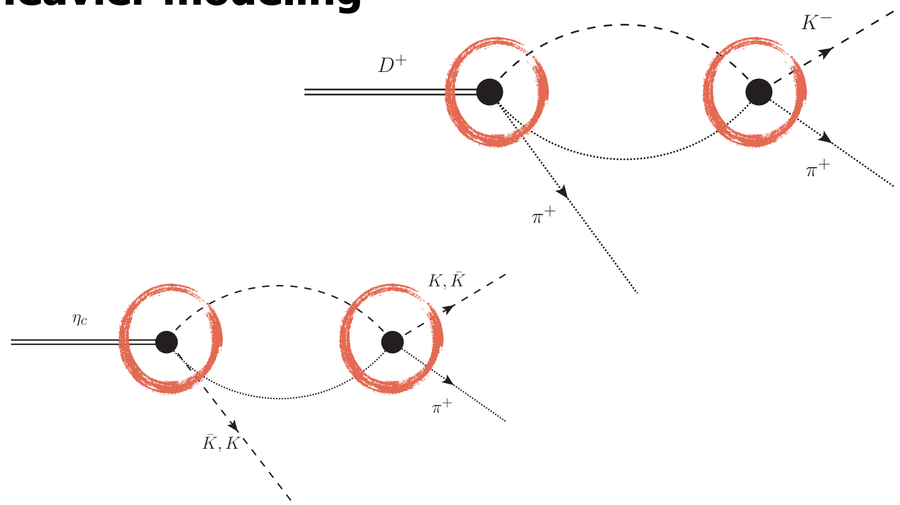
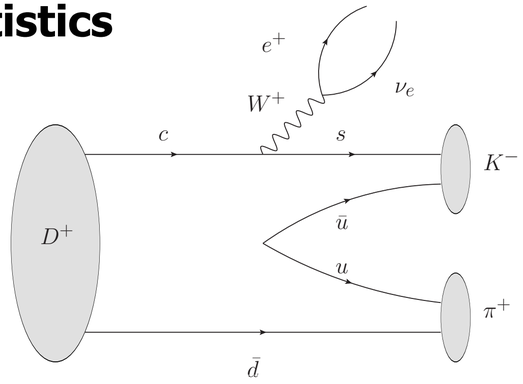


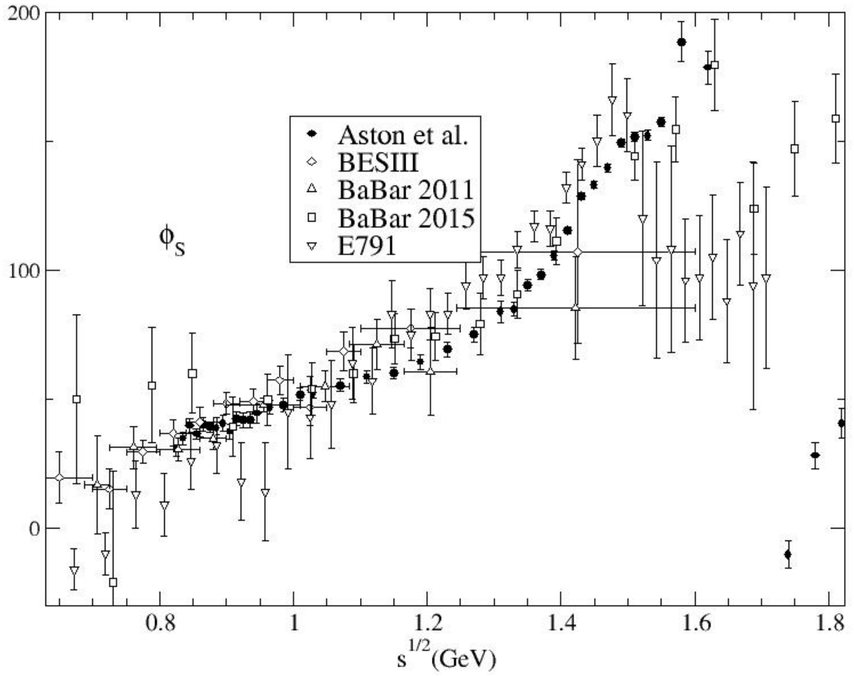
πK scattering

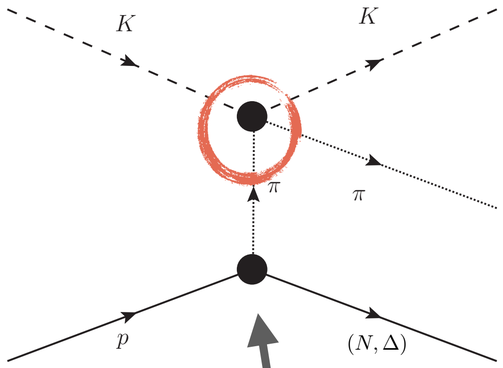
Heavier modeling

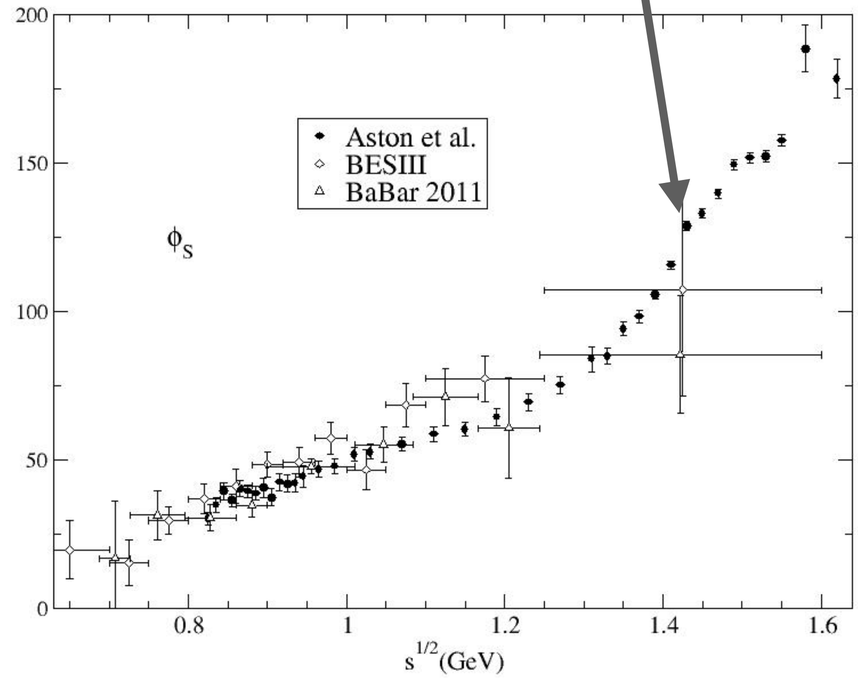


Not great statistics









Production offers most precise results, by far

πK scattering

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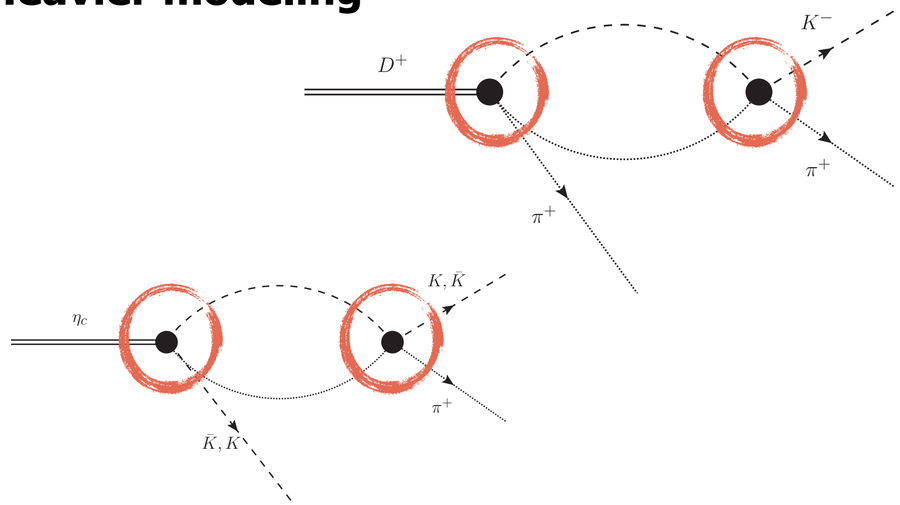
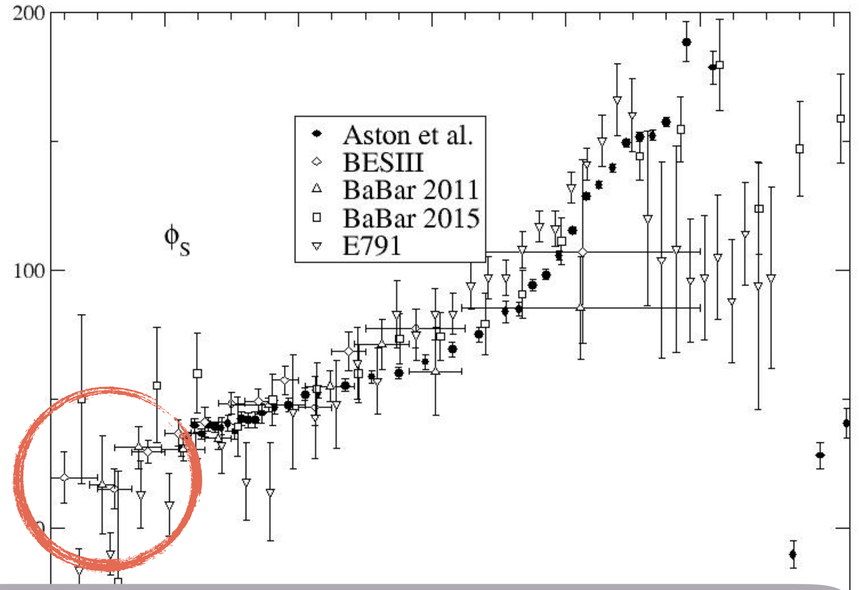
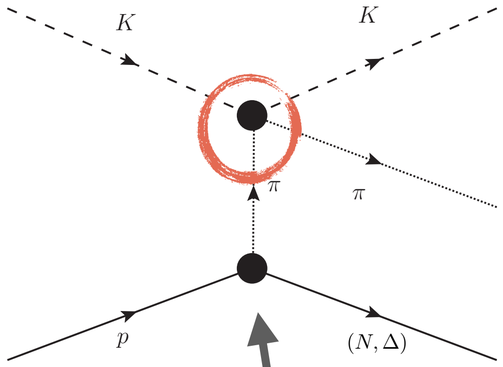
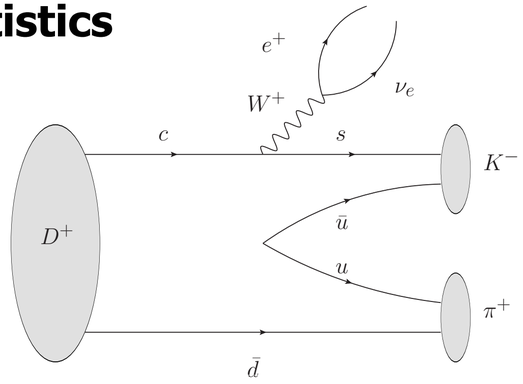


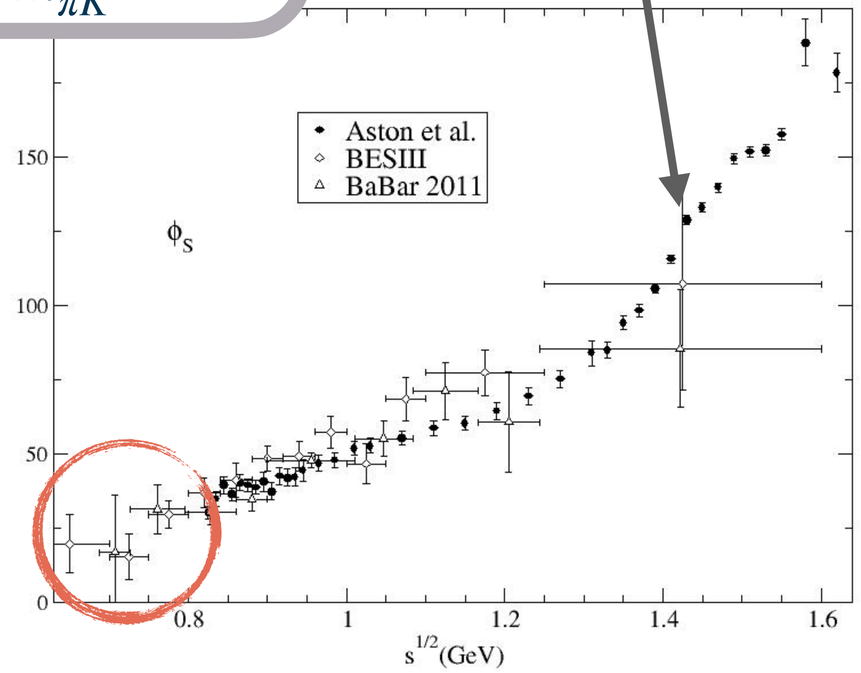




No data at low $m_{\pi K}$

Not great statistics





Production offers most precise results, by far

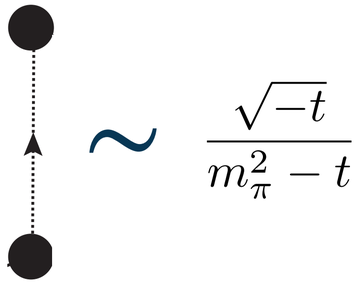
Challenge II

$$\frac{d\sigma}{dt}(s,t) \sim \sum |L_\lambda^{(\pm)}(s,t)|^2$$

We can have a single meson beam

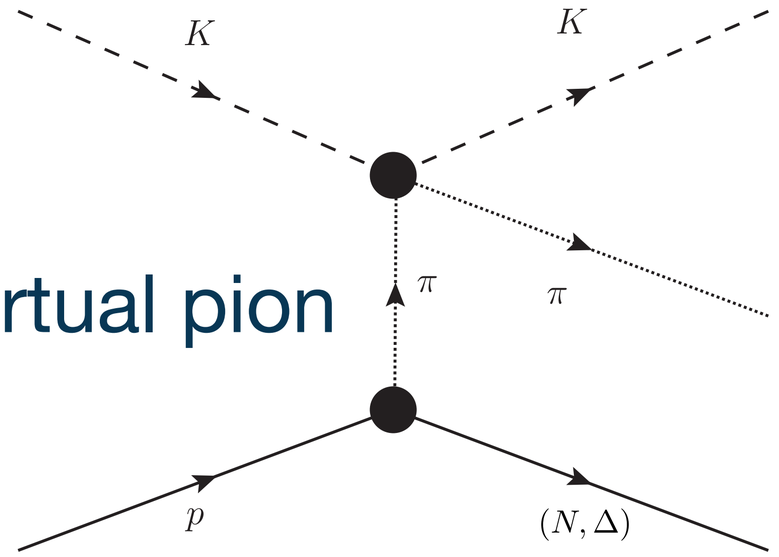
We want real pions, not virtual

What if we model the virtual pion?

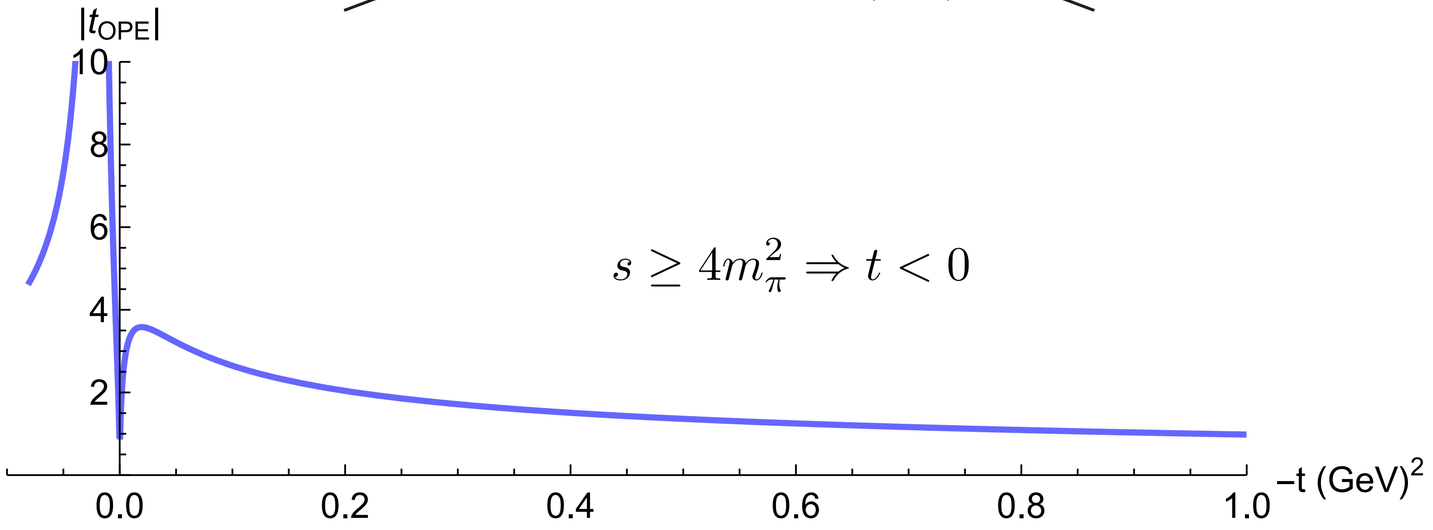


$$\sim \frac{\sqrt{-t}}{m_\pi^2 - t}$$

$$L_0(s,t) \sim f_L(s) \frac{\sqrt{-t}}{m_\pi^2 - t}$$



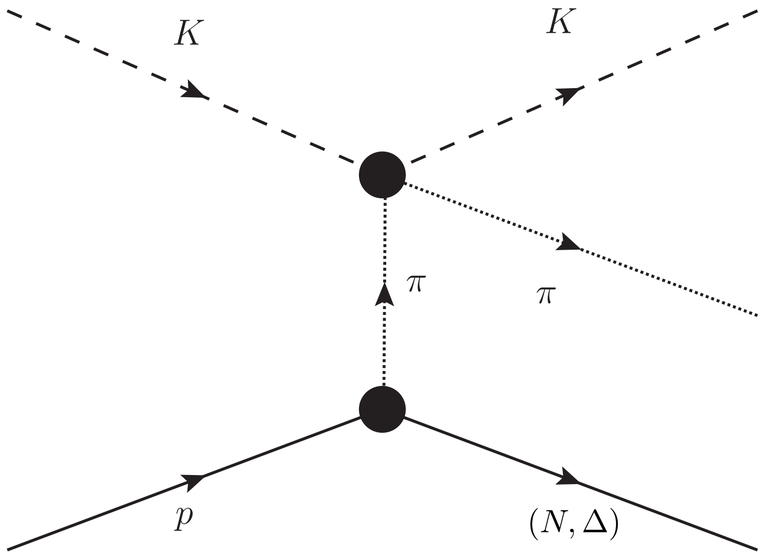
Virtual pion

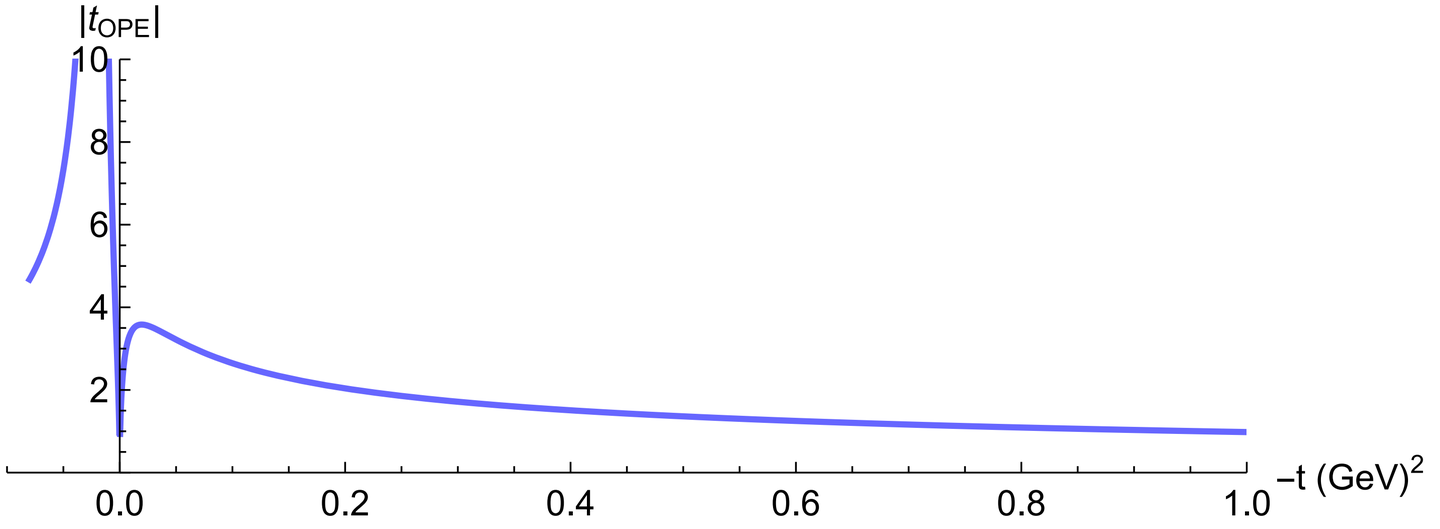


$$s \geq 4m_\pi^2 \Rightarrow t < 0$$

Challenge II

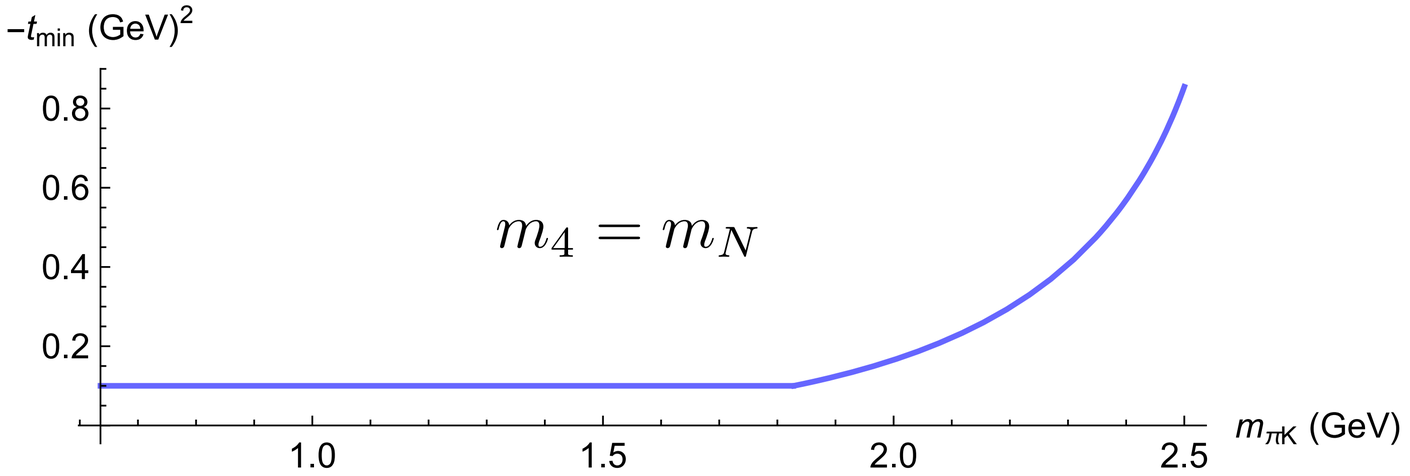
Not all t values are reachable





$$t_{min}(s') = \left[\frac{m_K^2 - m_{\pi K}^2 - m_N^2 + m_{(N,\Delta)}^2}{2\sqrt{s'}}\right]^2 - \left(p_{1\ \mathrm{cm}}(s') - p_{3\ \mathrm{cm}}(s')\right)^2$$

Not all theoretically reachable t values are measurable in practice



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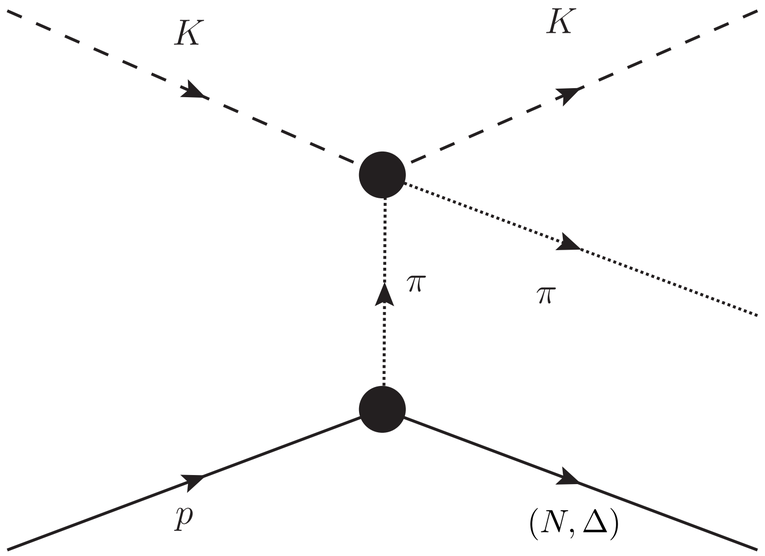

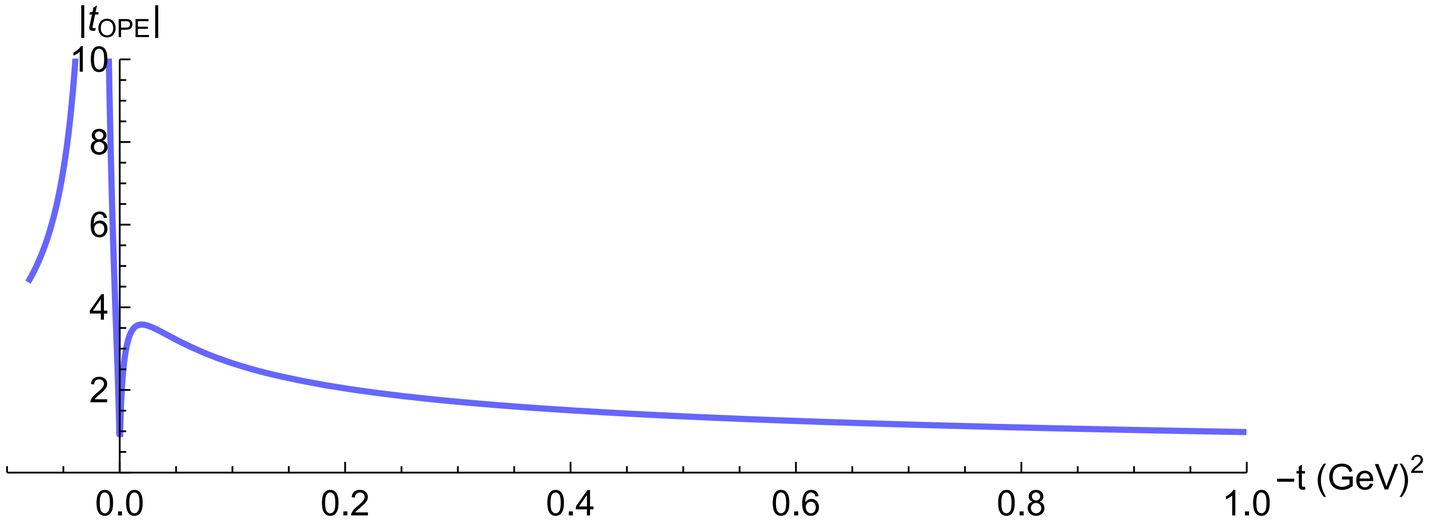

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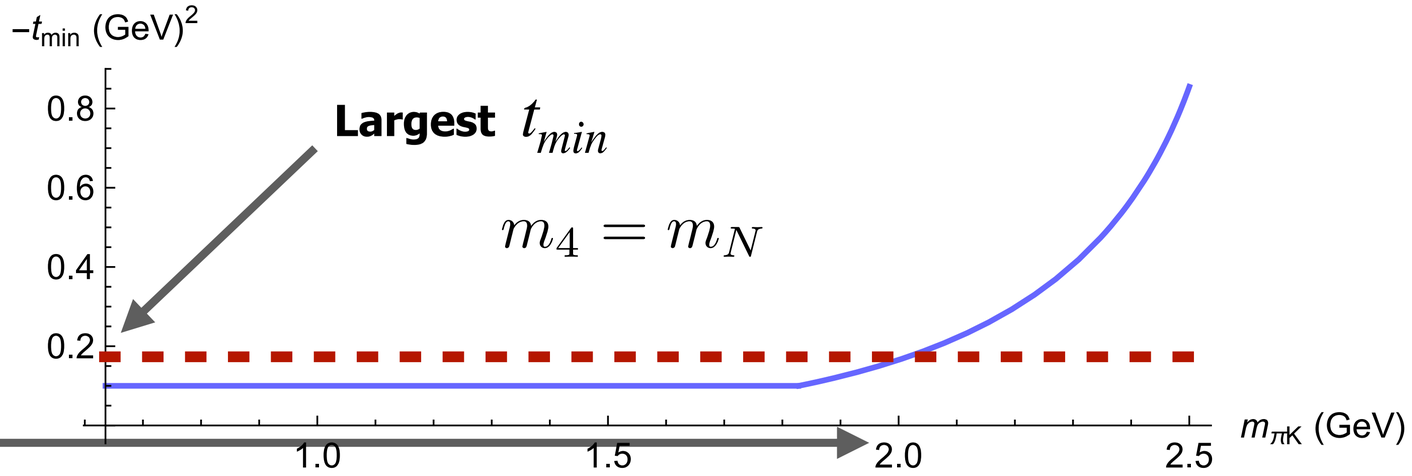
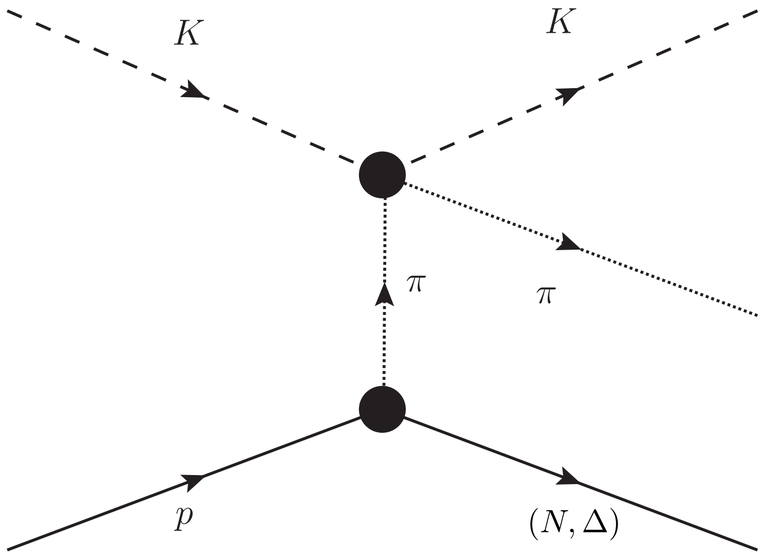


Largest resonance mass

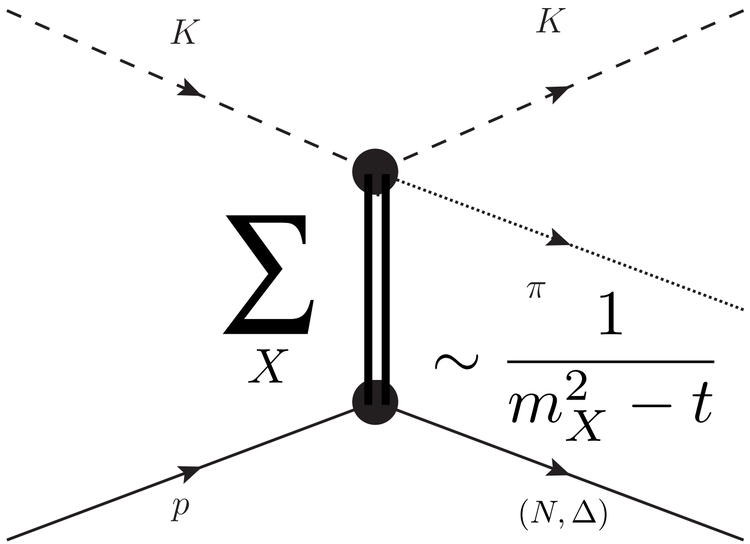
Challenge II

We exchange more than pions



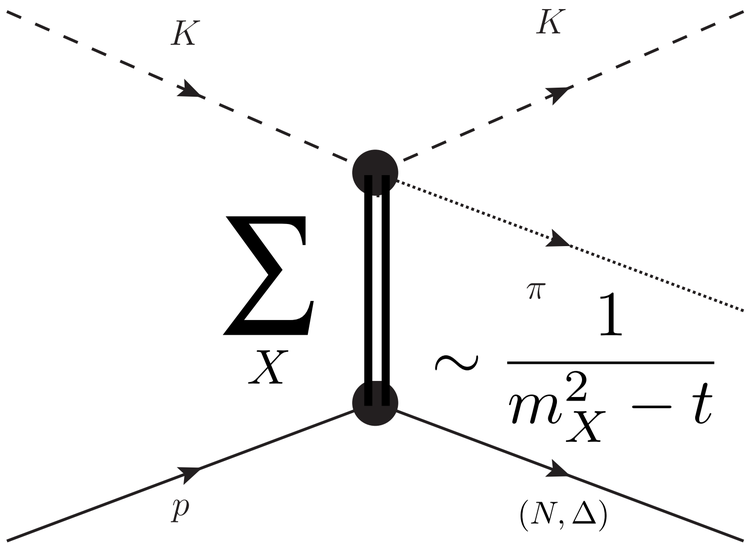
Challenge II

We exchange more than pions

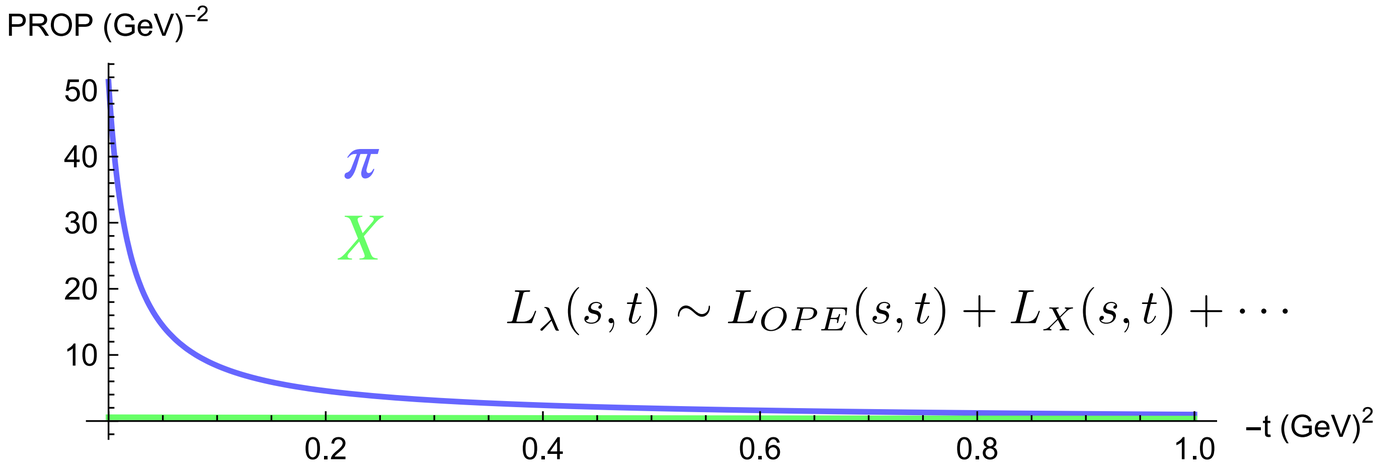


Challenge II

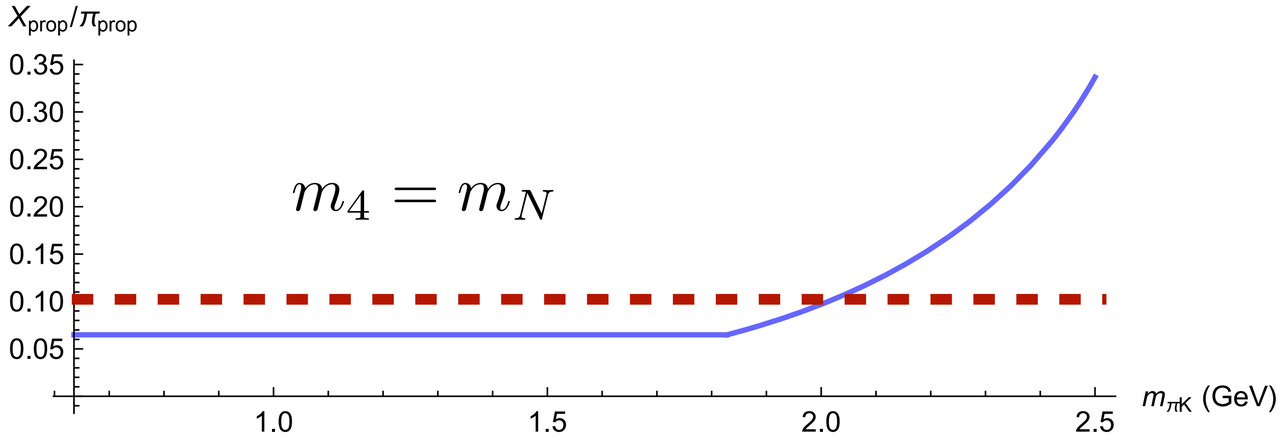
We exchange more than pions



The pion propagator dominates at low t



But remember our t_{min} might become large with $m_{\pi K}$

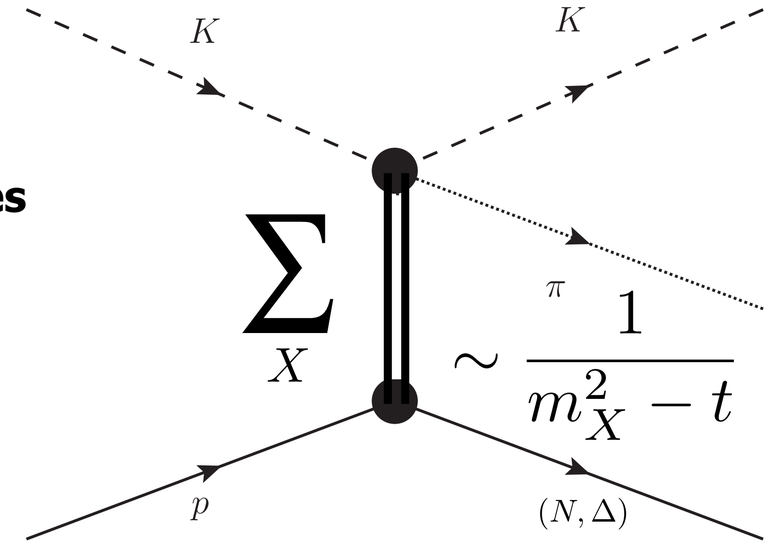


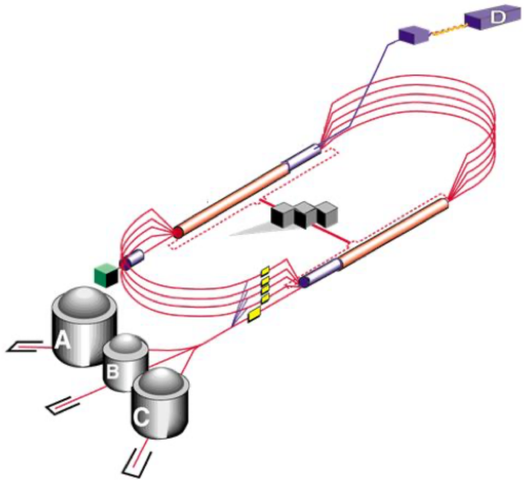
This crude estimation suggests that other exchanges need not be fully negligible with respect to the OPE for large masses

Solutions

Attract theoretical talent/experts on reaction theory/exchanges

Determine other possible exchange(s) with robustness





Can polarized targets help separate the exchange contributions?

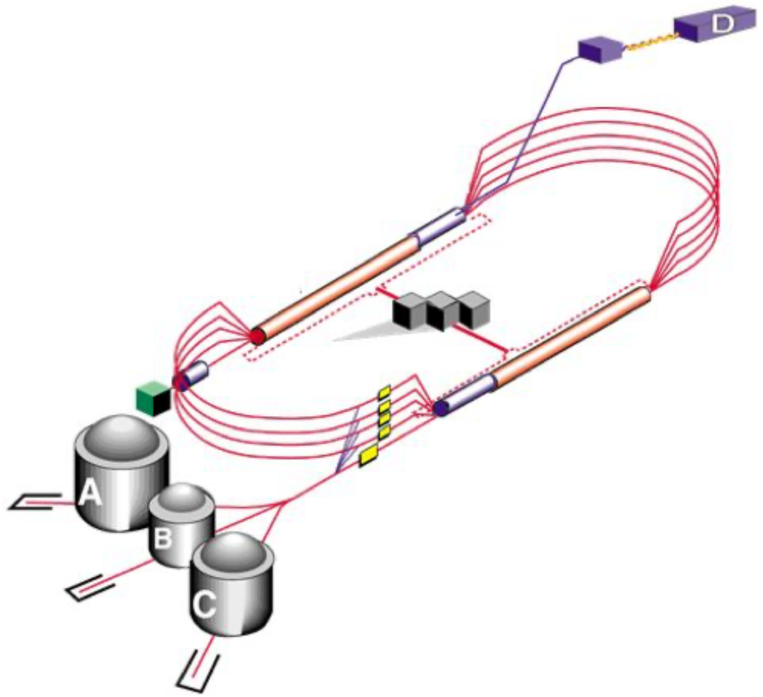
https://arxiv.org/pdf/hep-ph/9606362.pdf

Increase the energy of the Kaon beam

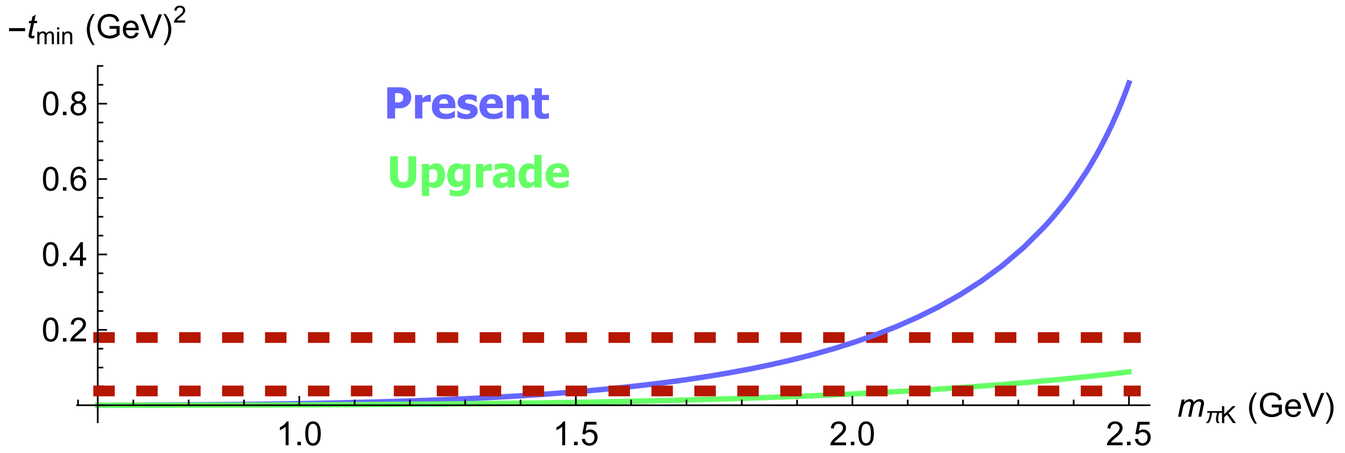
Future upgrade??

Future??

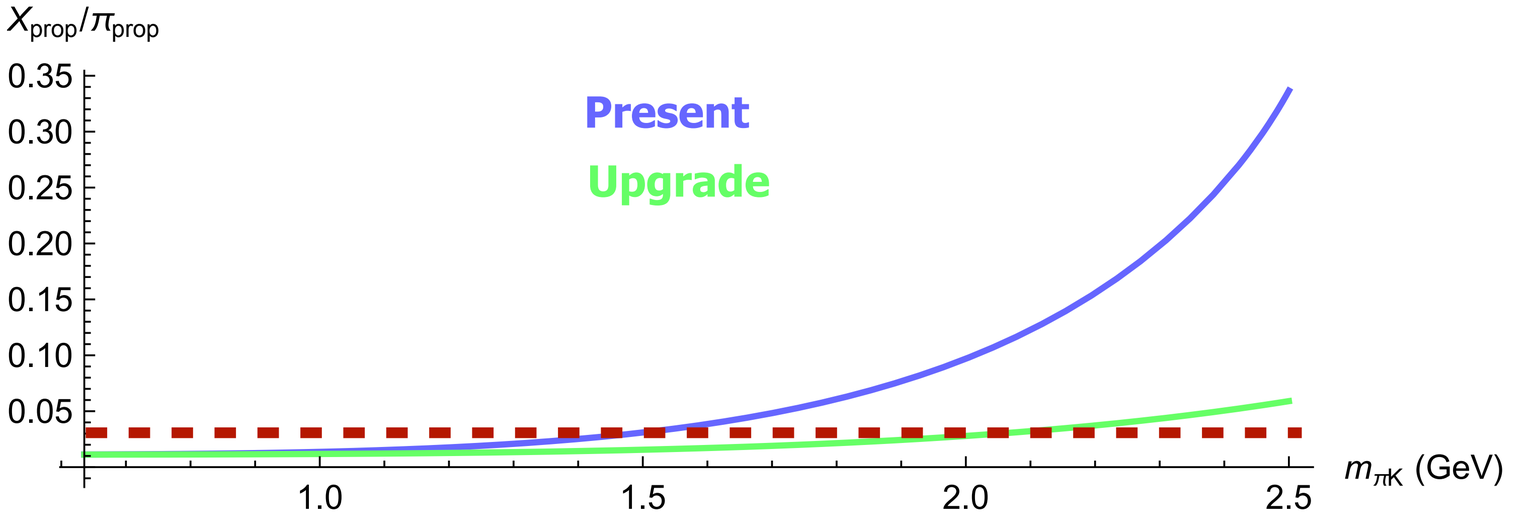
Increase the energy of the Kaon beam



Much smaller t_{min} achievable



Much smaller contribution from other exchanges



Conclusions

6 out of 10 K^* resonances below or around 2 GeV are poorly known

Related to ChPT, CP-violating decays, B decays, CKM and BSM searches

The setup and current models should work very well at low $m_{\pi K}$

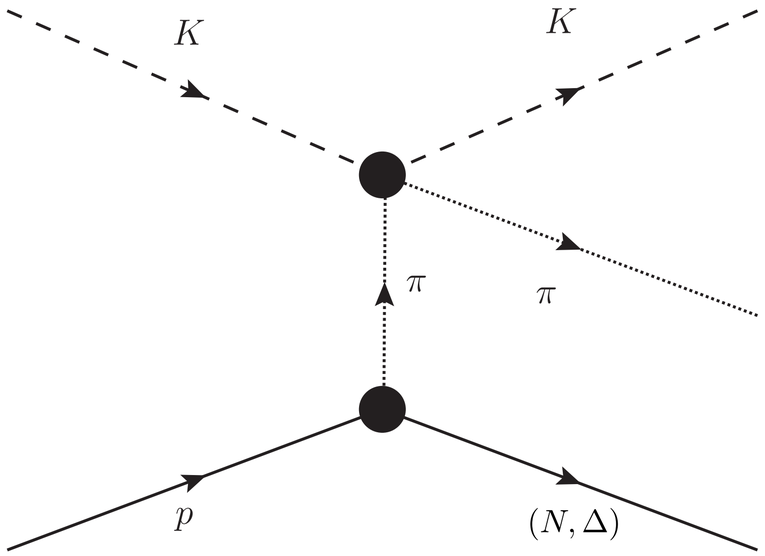
Three possible solutions for tackling the exchanges at high $m_{\pi K}$:

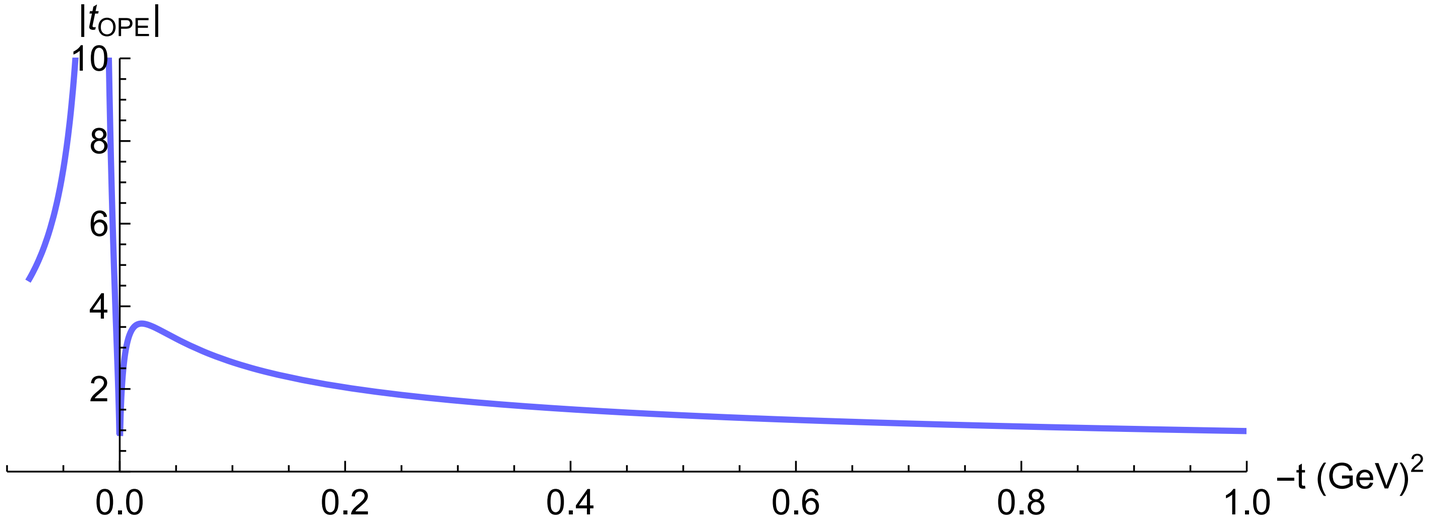
1. **Elaborate theoretical input**
2. **Could polarized targets help factorize the exchanges?**
3. **Future JLab upgrade**

Thank you!!

Challenge II

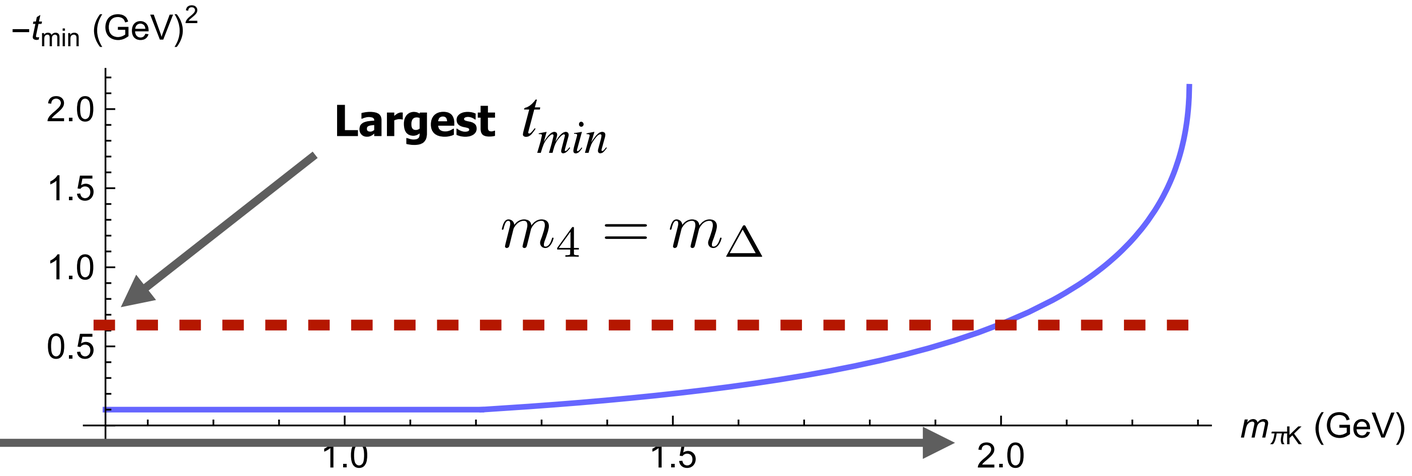
Not all t values are reachable





$$t_{min}(s') = \left[\frac{m_K^2 - m_{\pi K}^2 - m_N^2 + m_{(N,\Delta)}^2}{2\sqrt{s'}}\right]^2 - \left(p_{1\ \mathrm{cm}}(s') - p_{3\ \mathrm{cm}}(s')\right)^2$$

Not all theoretically reachable t values are measurable in practice



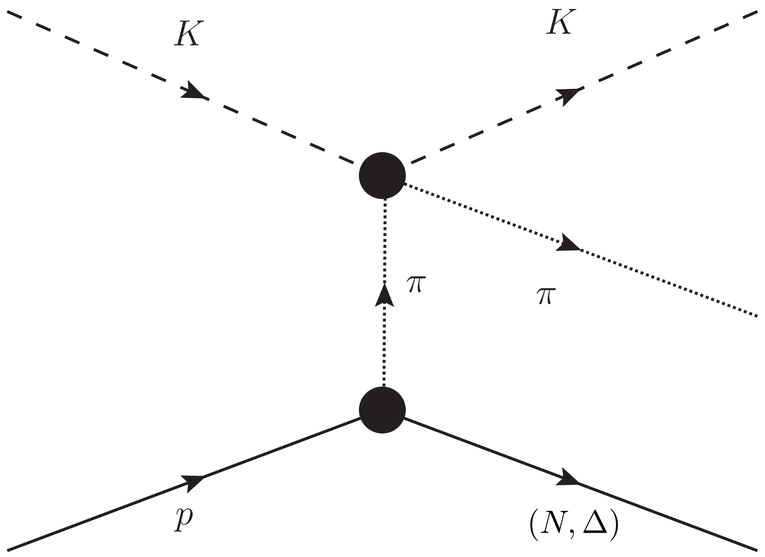
Largest resonance mass

Isospin separation

We can measure different isospin combinations

$$L_0(s,t) \sim f_L(s)\frac{\sqrt{-t}}{m_\pi^2 - t}$$

$$f_L(s) = x f_{1/2}(s) + y f_{3/2}(s)$$



To separate $I = 1/2, 3/2$ we need to measure at least a final state with K_L

$$K_L\pi^+ \to K_L\pi^+ : \frac{a^2}{3} + \frac{2b^2}{3}$$

$$K_L\pi^+ \to K_S\pi^+ : \frac{a^2}{3} - \frac{b^2}{3}$$

$$K_L\pi^+ \to K^+\pi^0 : -\frac{a^2}{3} + \frac{b^2}{3}$$

$$K_L\pi^0 \to K_L\pi^0 : \frac{a^2}{3} + \frac{2b^2}{3}$$

$$K_L\pi^0 \to K^+\pi^- : -\frac{a^2}{3} + \frac{b^2}{3}$$

$$K_L\pi^0 \to K^-\pi^+ : -\frac{a^2}{3} + \frac{b^2}{3}$$

$$K_L\pi^- \to K_L\pi^- : \frac{a^2}{3} + \frac{2b^2}{3}$$

$$K_L\pi^- \to K_S\pi^- : -\frac{a^2}{3} + \frac{b^2}{3}$$

$$K_L\pi^- \to K^-\pi^0 : -\frac{a^2}{3} + \frac{b^2}{3}$$

Challenge II

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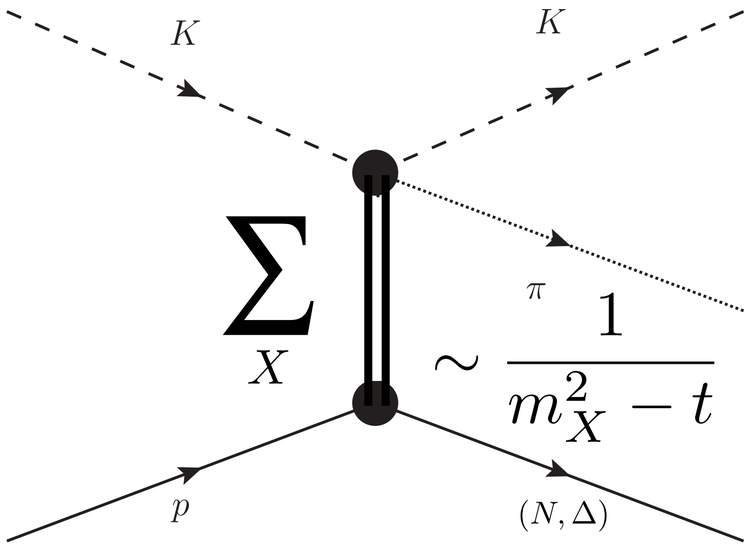

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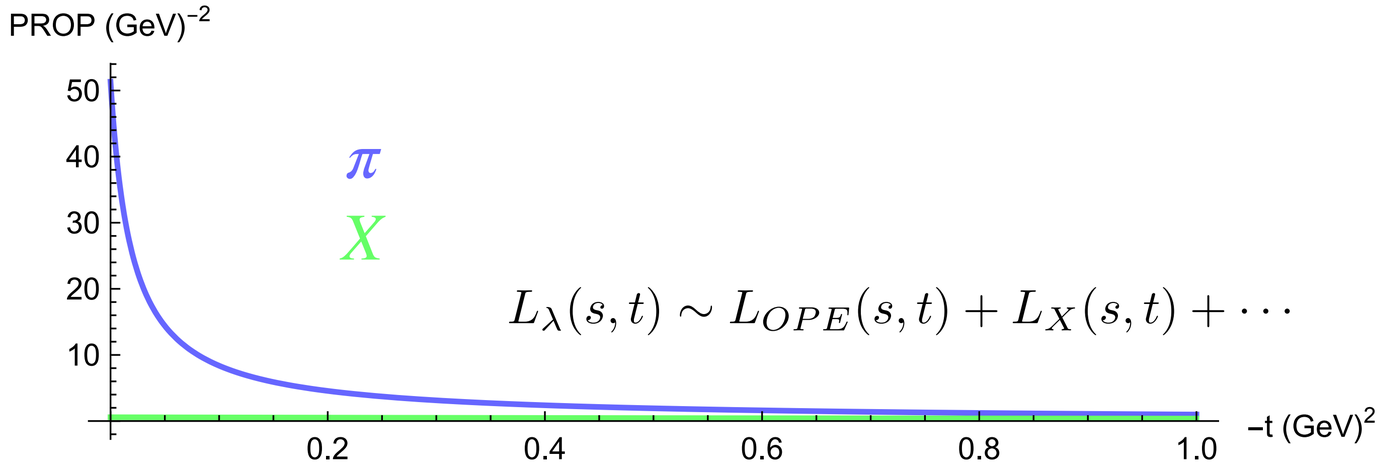

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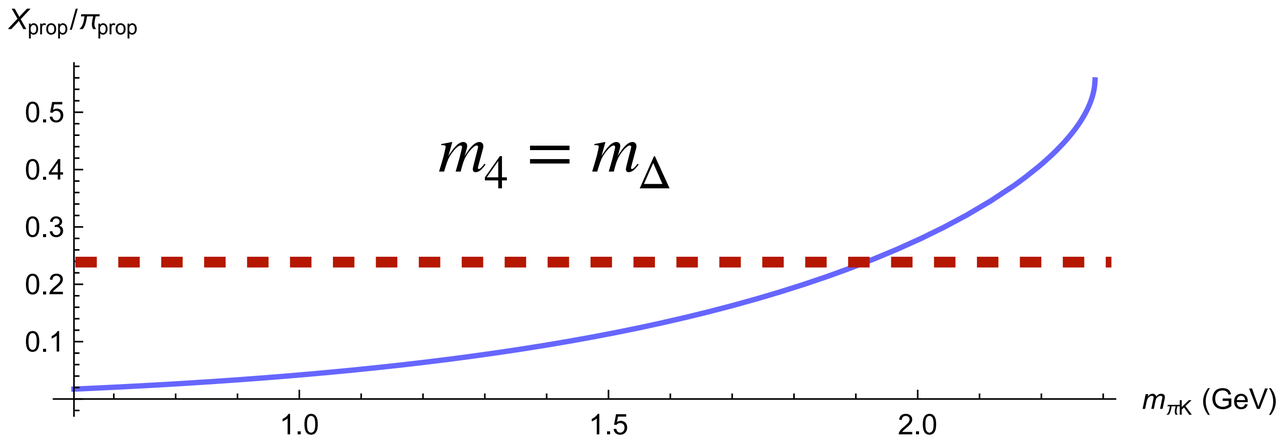
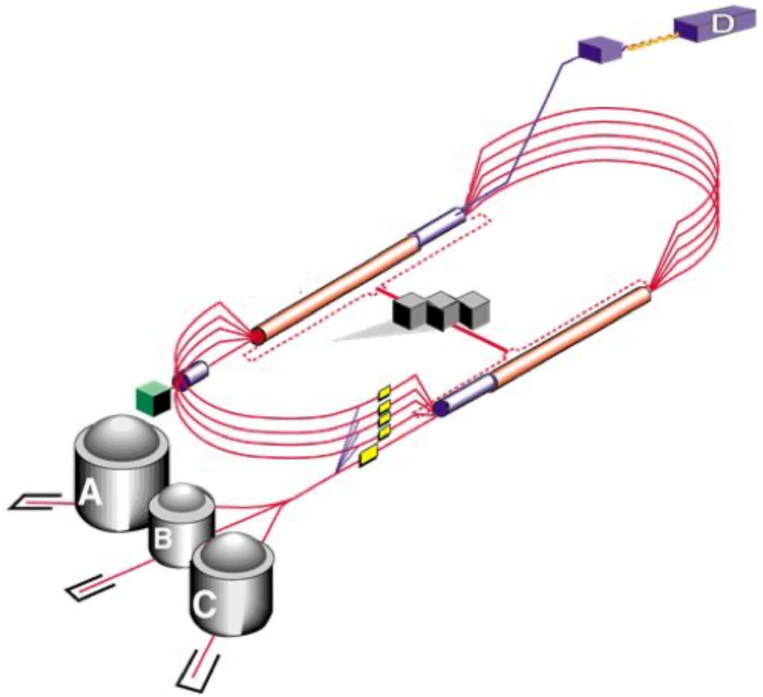


This, very crude, pessimistic estimation suggests that other exchanges need not be negligible with respect to the OPE for large masses

Future??

Increase the energy of the Kaon beam



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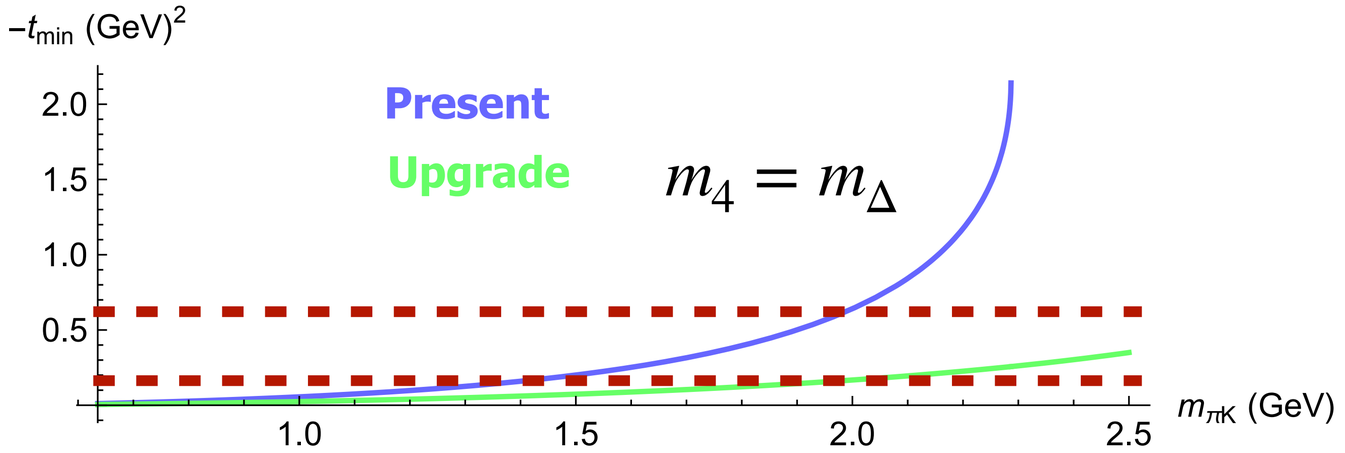
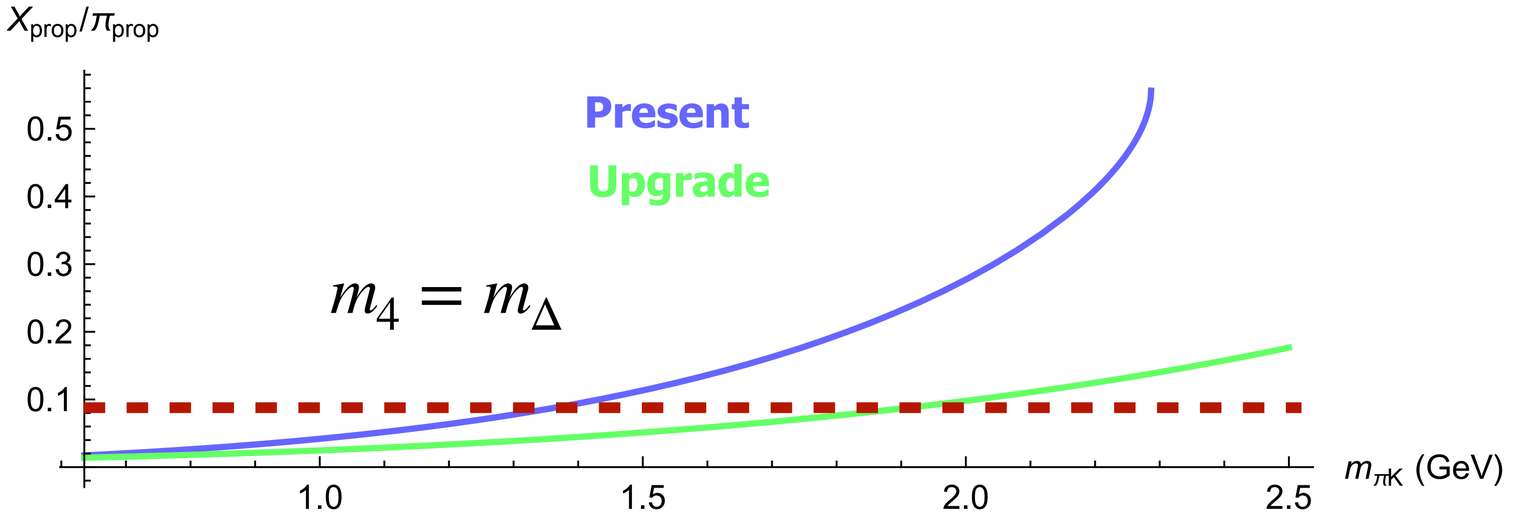
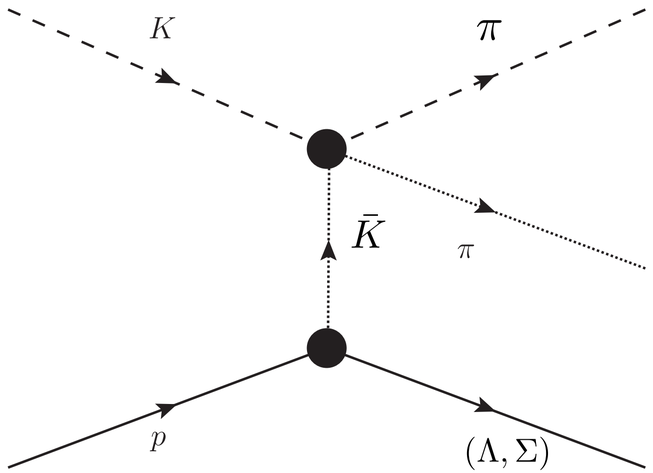


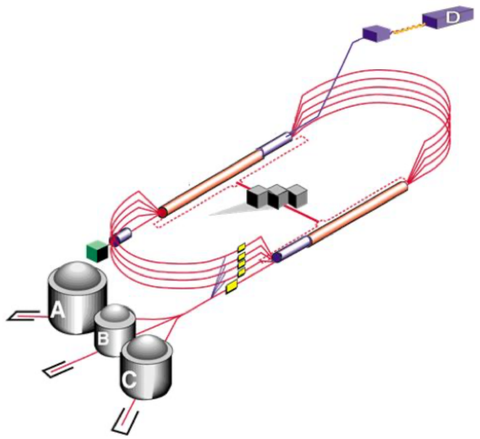
Much smaller contribution from other exchanges



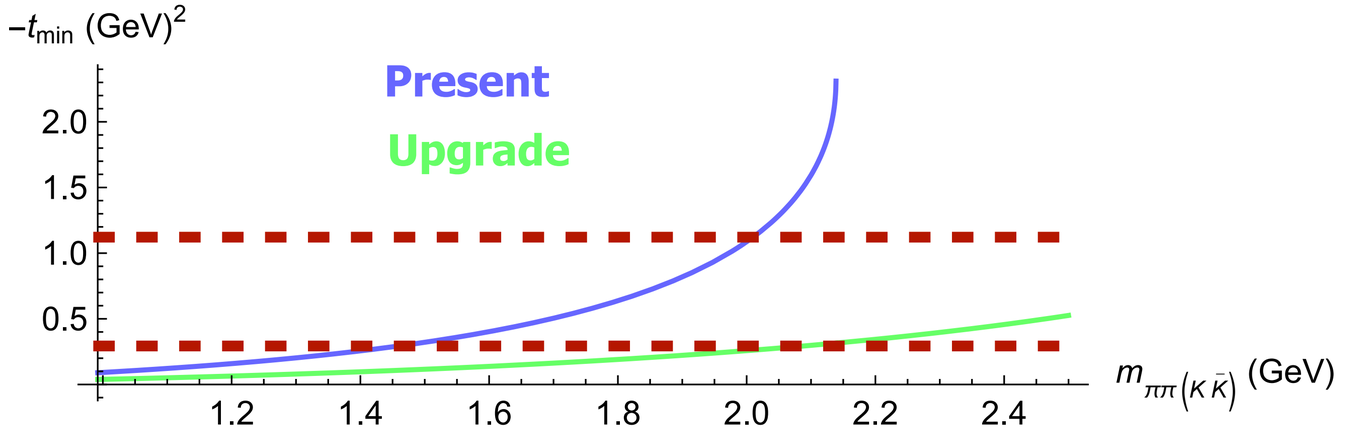
Future??

New measurements??

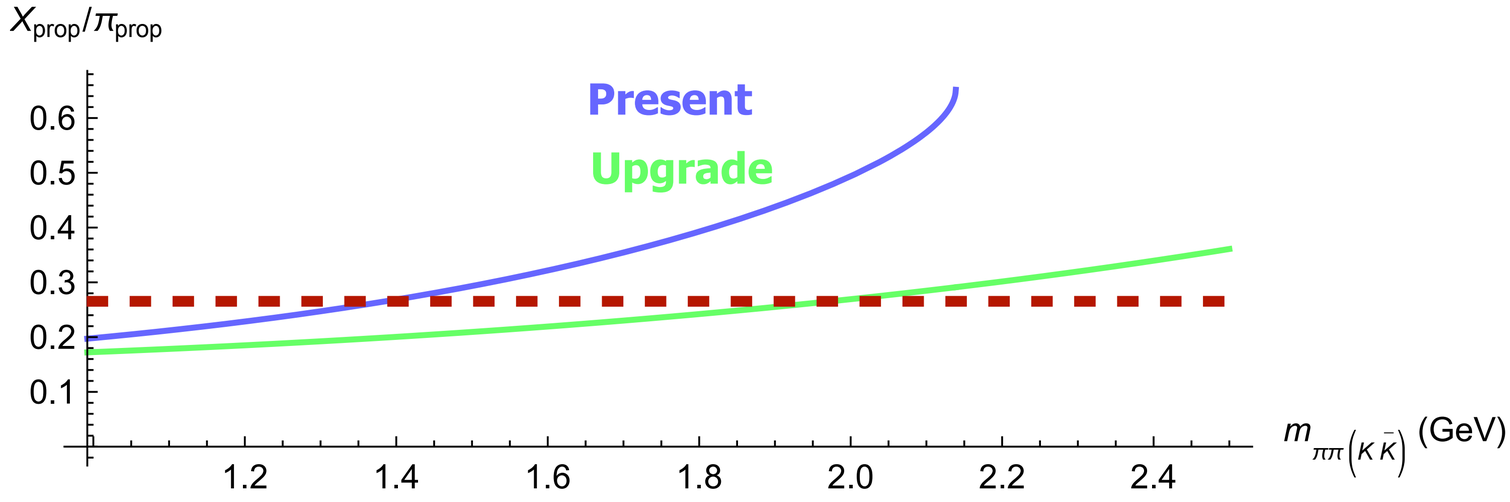




t_{min} **much larger than before**



Next possible exchanges closer in mass

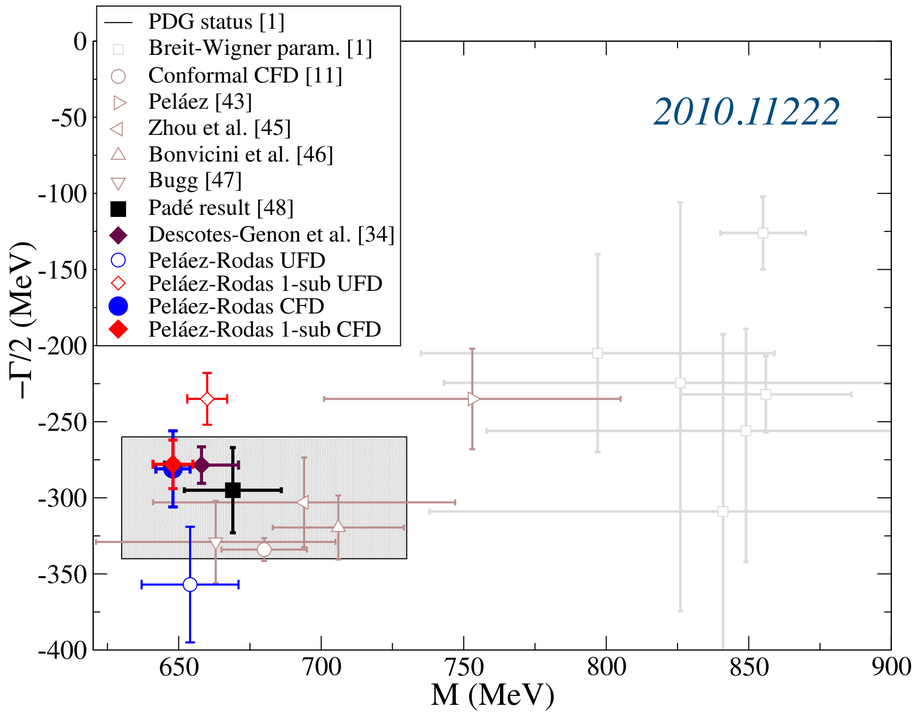


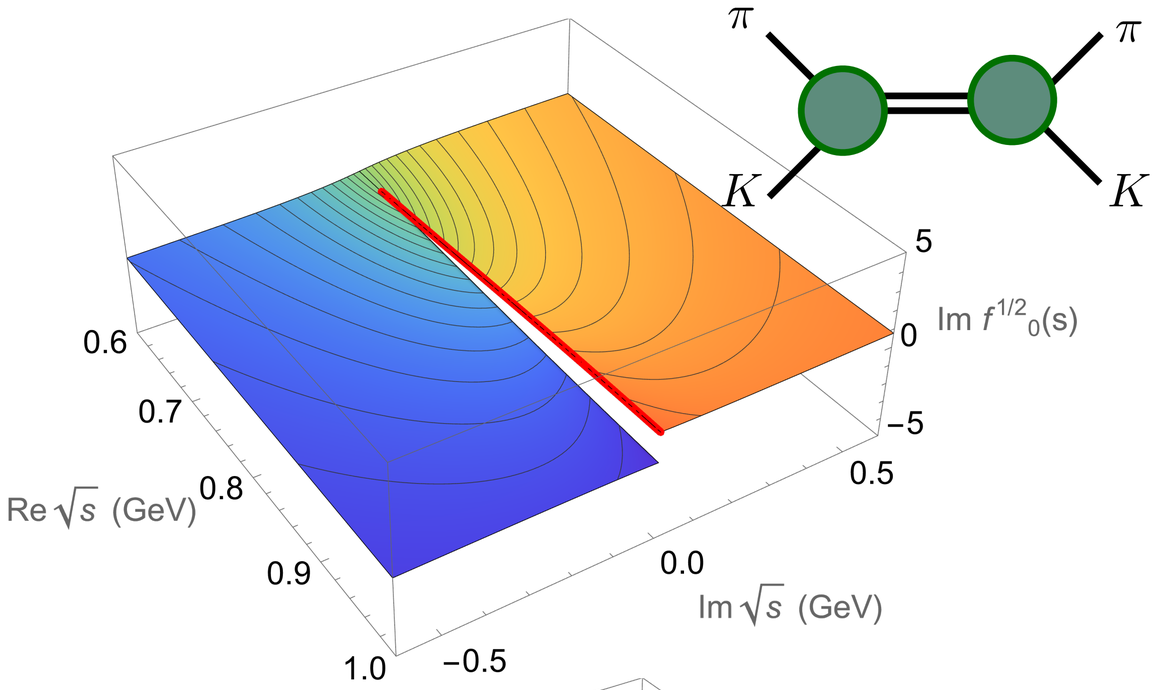
Scattering

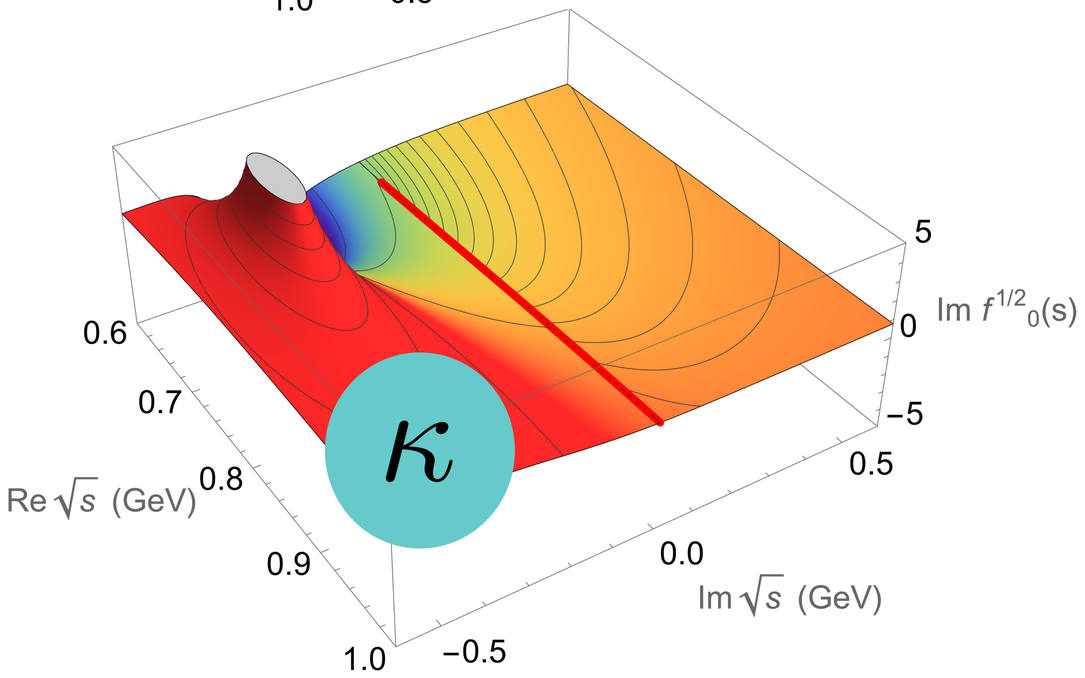
Definitely not a BW

$$t_\ell(s) \sim ??$$

What's this??







Scattering

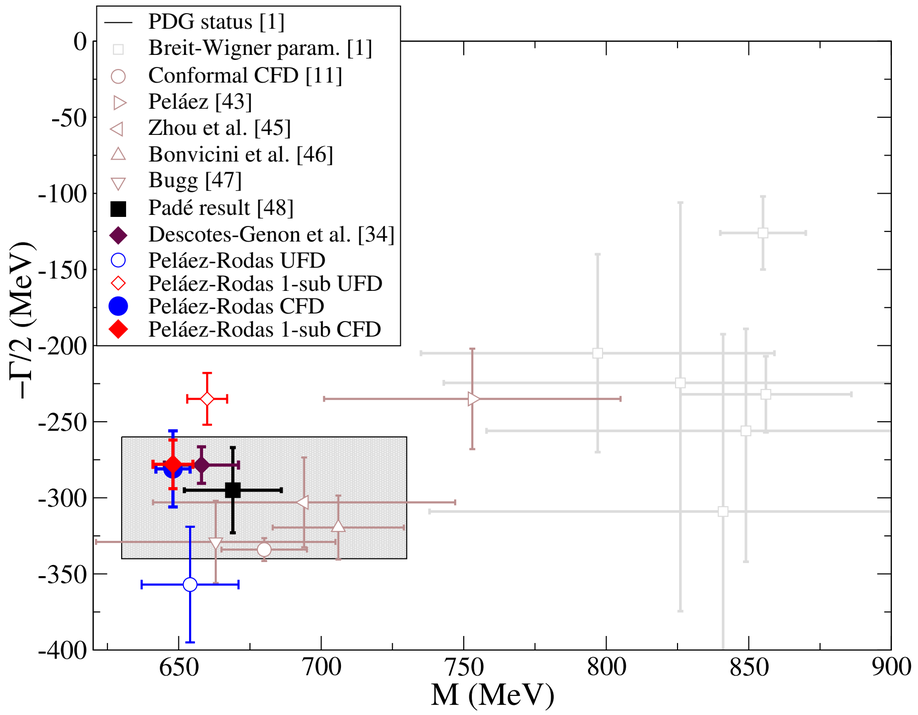
Definitely not a BW

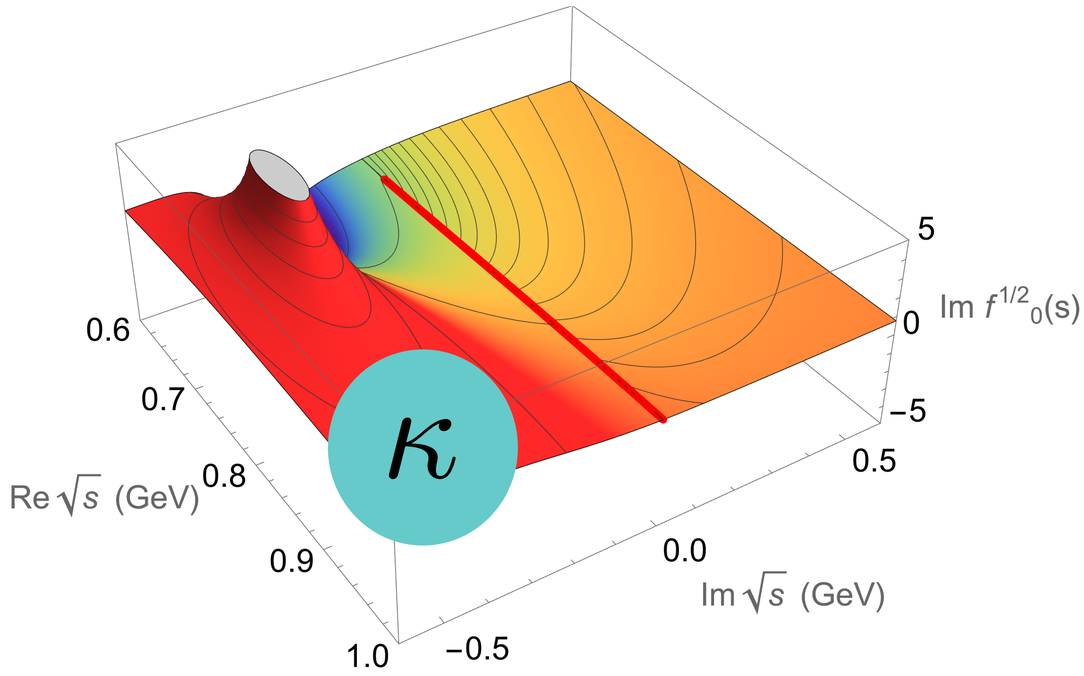
$$t_\ell(s) \sim ??$$

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

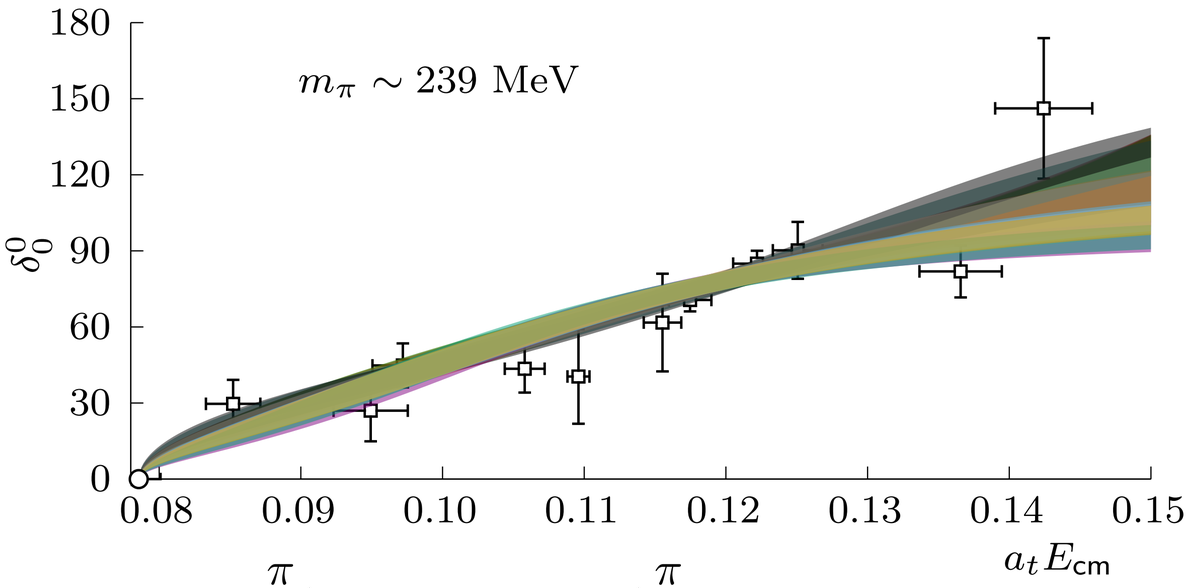
PDG 1967

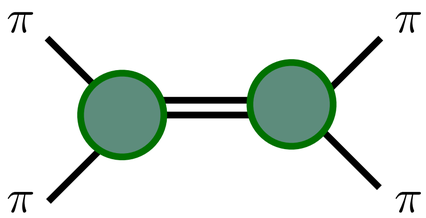
What's this??





$\pi\pi$ scattering



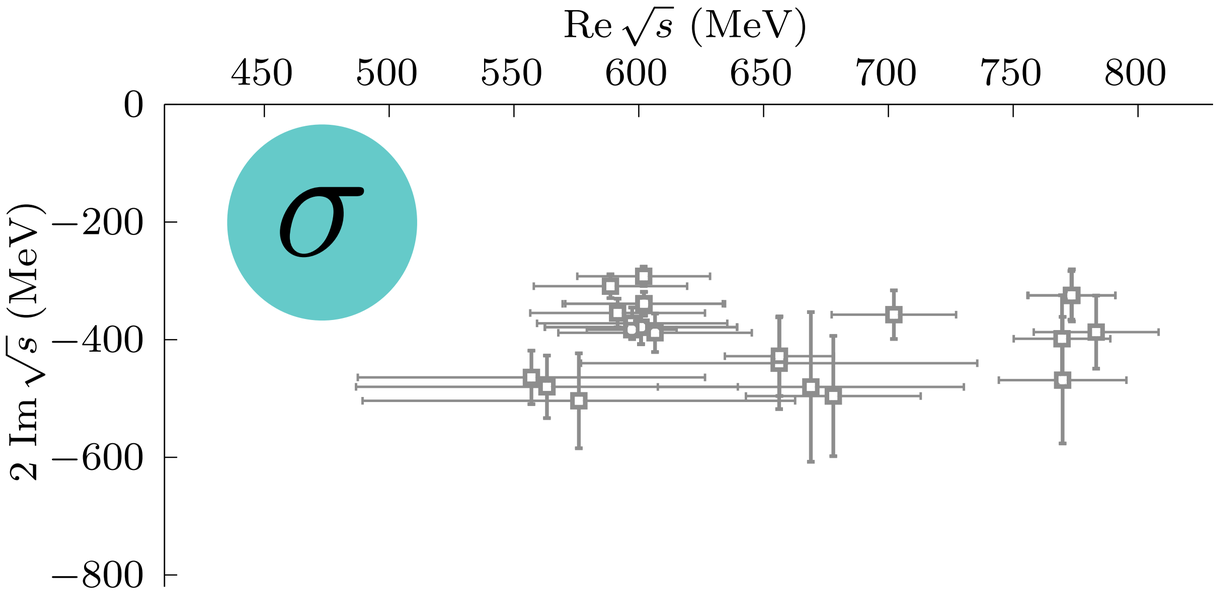


JRP talk

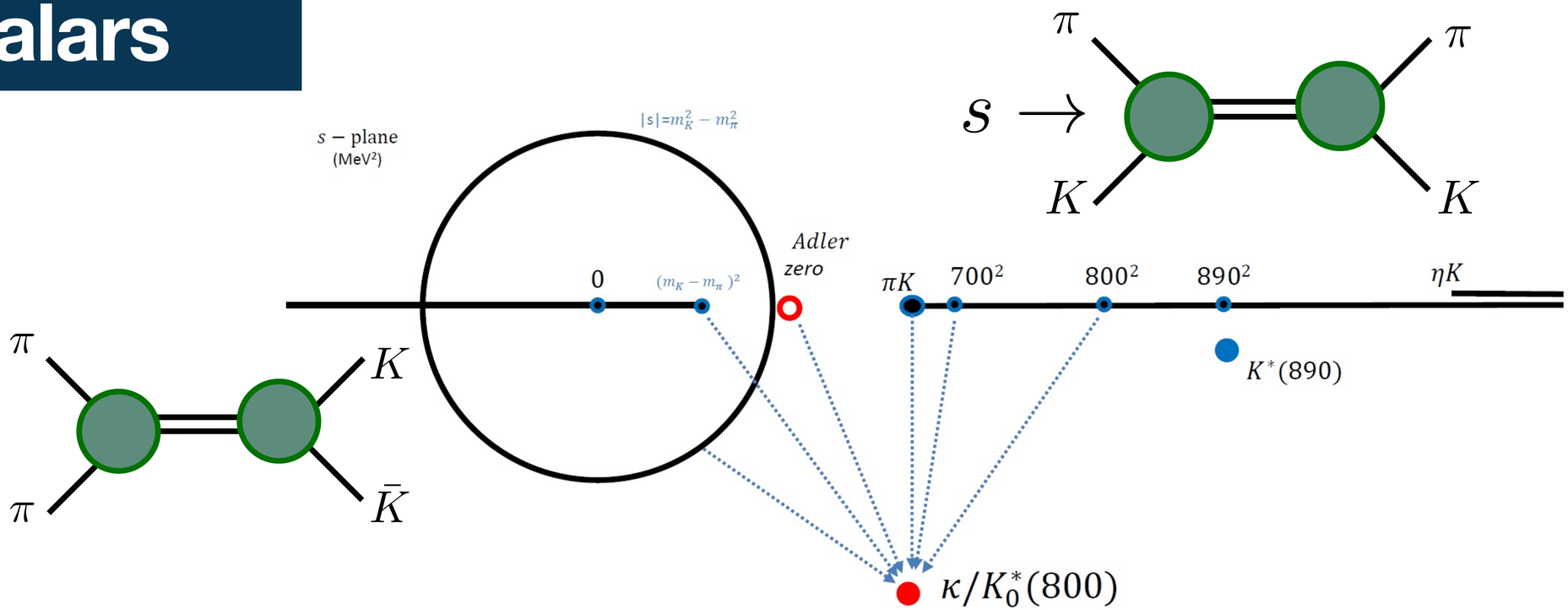
Problem shared with ALL Lattice QCD calculations

Innocent-looking data, around 20 compatible line shapes

The pole positions are not compatible



Light Scalars



Pole position depends on many structures

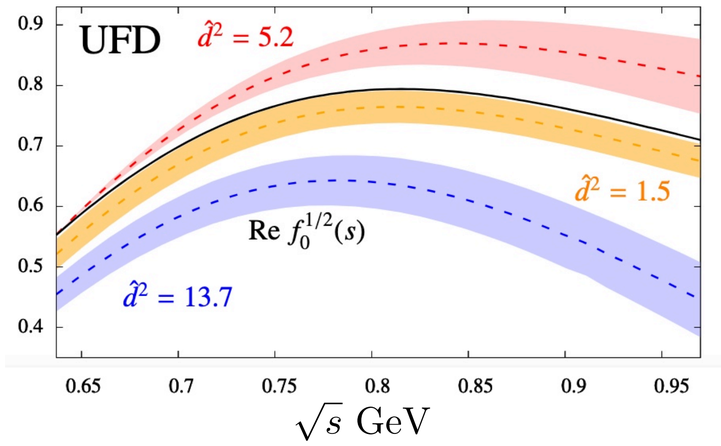
Data on the right-hand cut (RHC) ↔ Unitarity

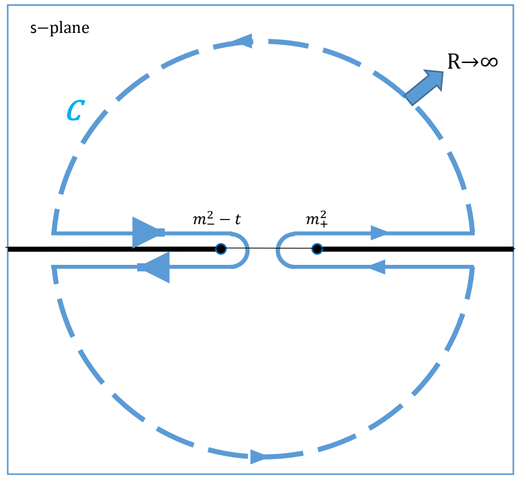
Low energy expansion

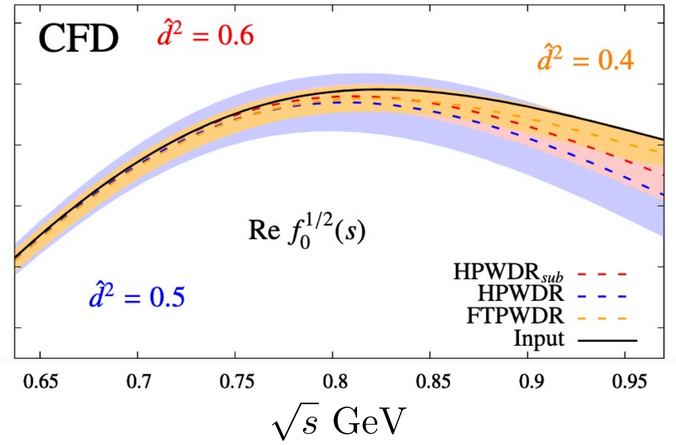
Adler Zero

Left-hand cut

Light Scalars





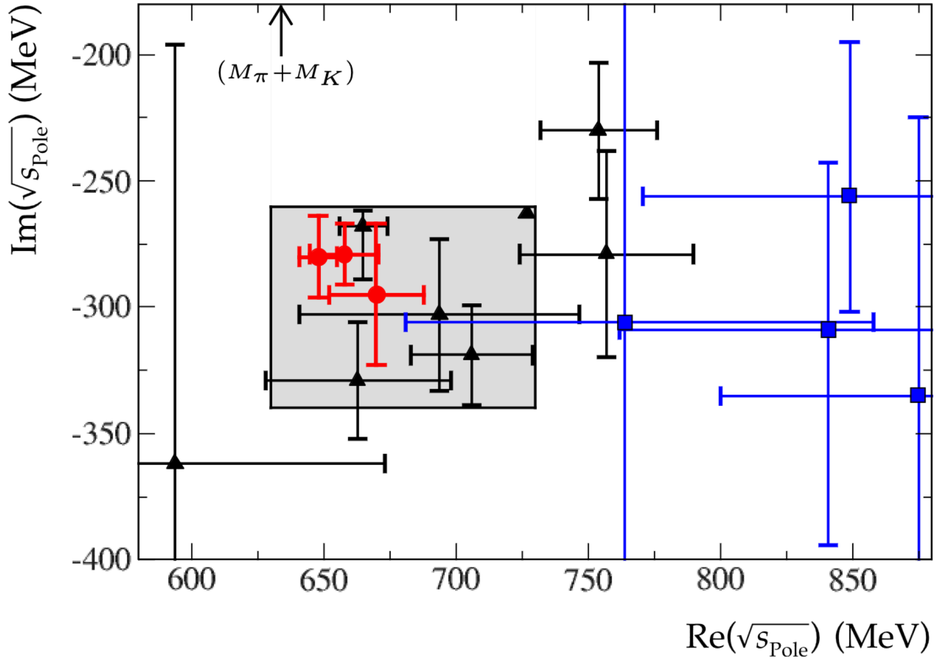


We use the result of these integral equations to extract our poles

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

The κ has just been recently accepted

"κ accepted"
PDG

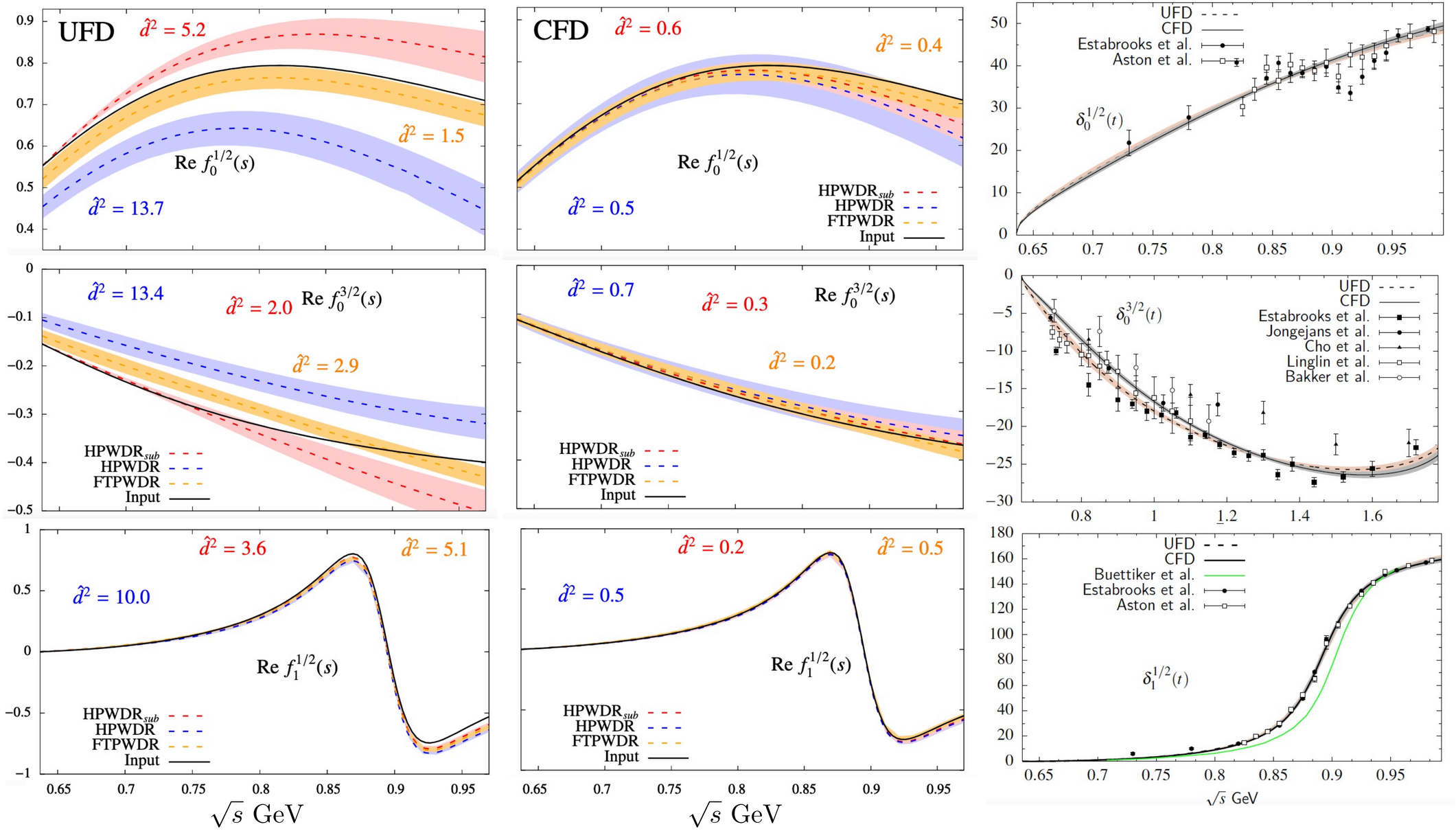


πK scattering

Make $Fit \rightarrow In$ $DR \rightarrow Out$ compatible

Vary the fits a bit

$f_\ell^I(s)$



πK scattering

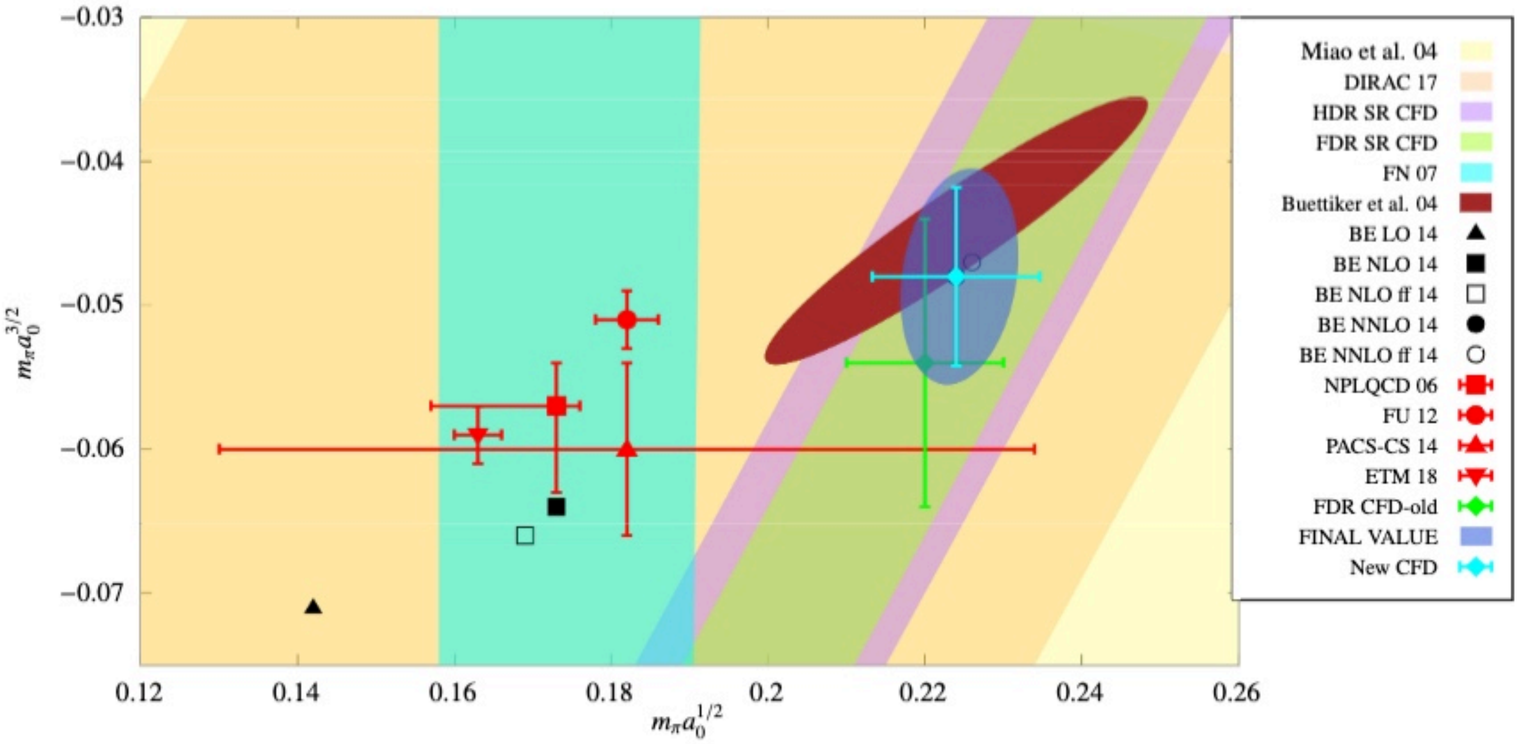
Model-independent results

Dispersive scattering lengths

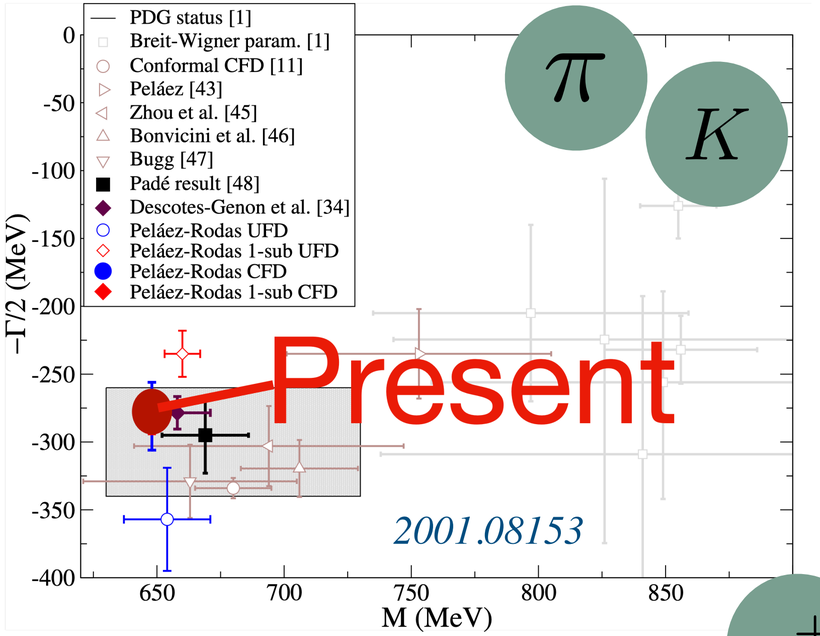
$$a_0^- = \frac{m_\pi m_K}{2\pi^2 m_+} \int_{m_+^2}^{\infty} \frac{\mathrm{Im}\, F^-(s')}{(s'-m_-^2)(s'-m_+^2)} ds'$$

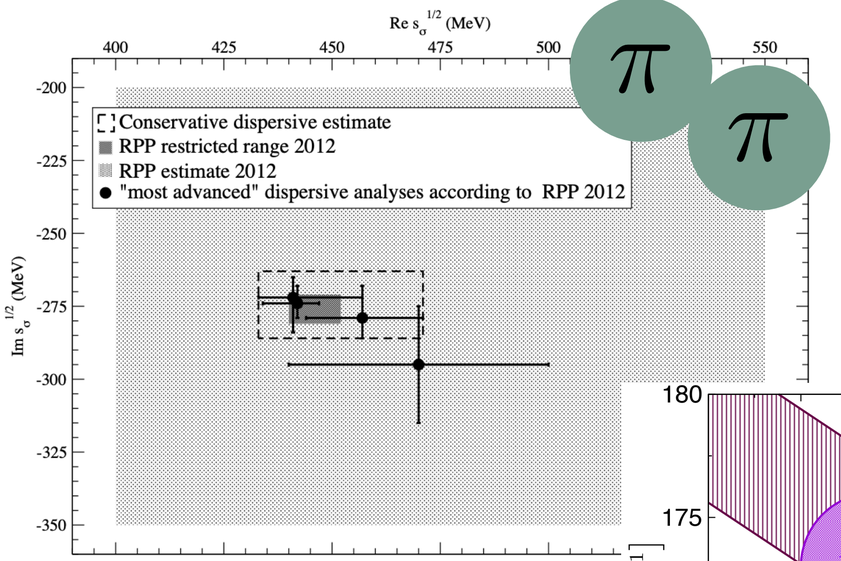
	FINAL	CFD	Paris group
$a_0^{1/2}$	0.224±0.008	0.224±0.011	0.224±0.022
$a_0^{3/2}$	-0.0480±0.0056	-0.048±0.006	-0.0448± 0.0077

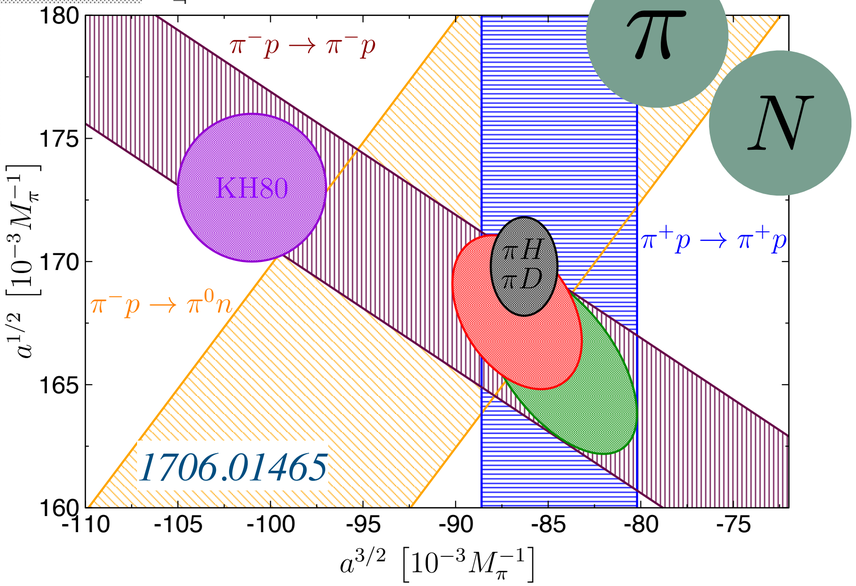
Tension between lattice QCD and dispersive results!!

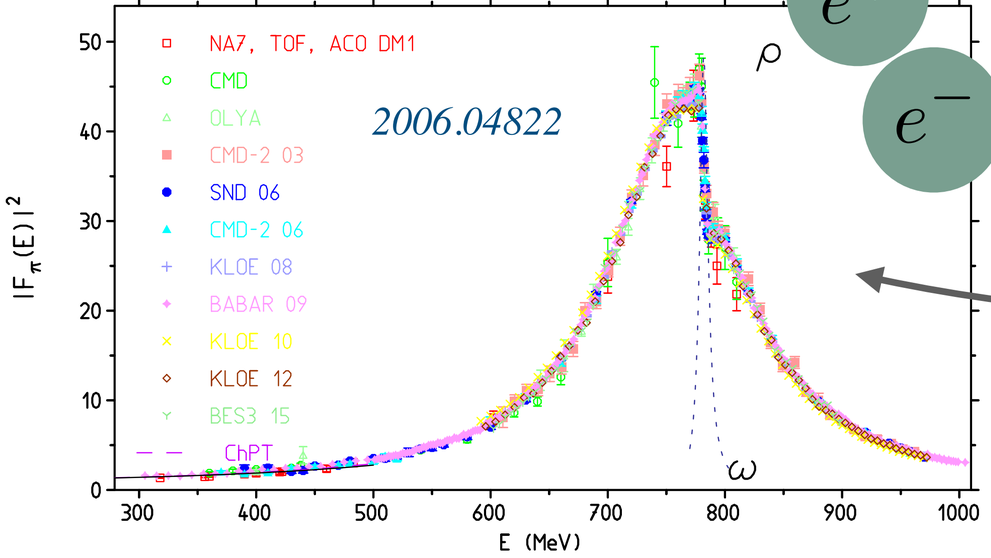


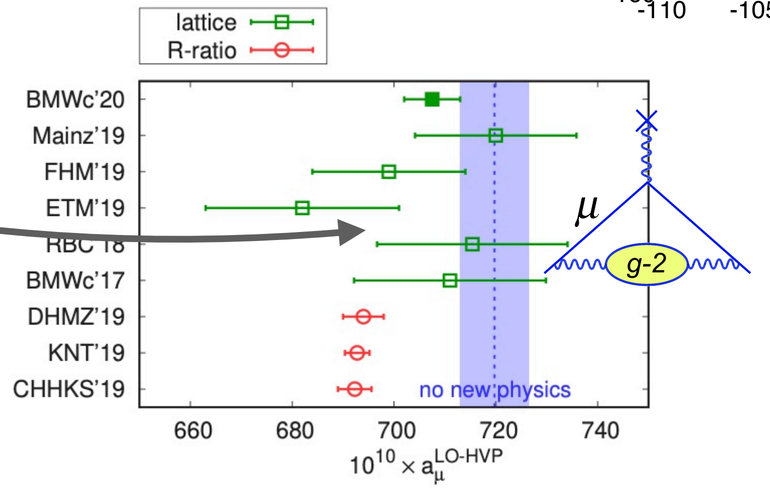
Dispersive analyses











And others…