Hyperon resonances in radiative kaon capture

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Overview

- Motivation
  - Baryon resonances (N and Y)
  - Missing resonances
  - Strangeness production in the search for nucleon resonances
- Kaon production vs. Kaon capture
- Isobar model: background problem
- The *Regge-plus-resonance* model for kaon production
- RPR for radiative kaon capture: background contribution
- Conclusions and outlook

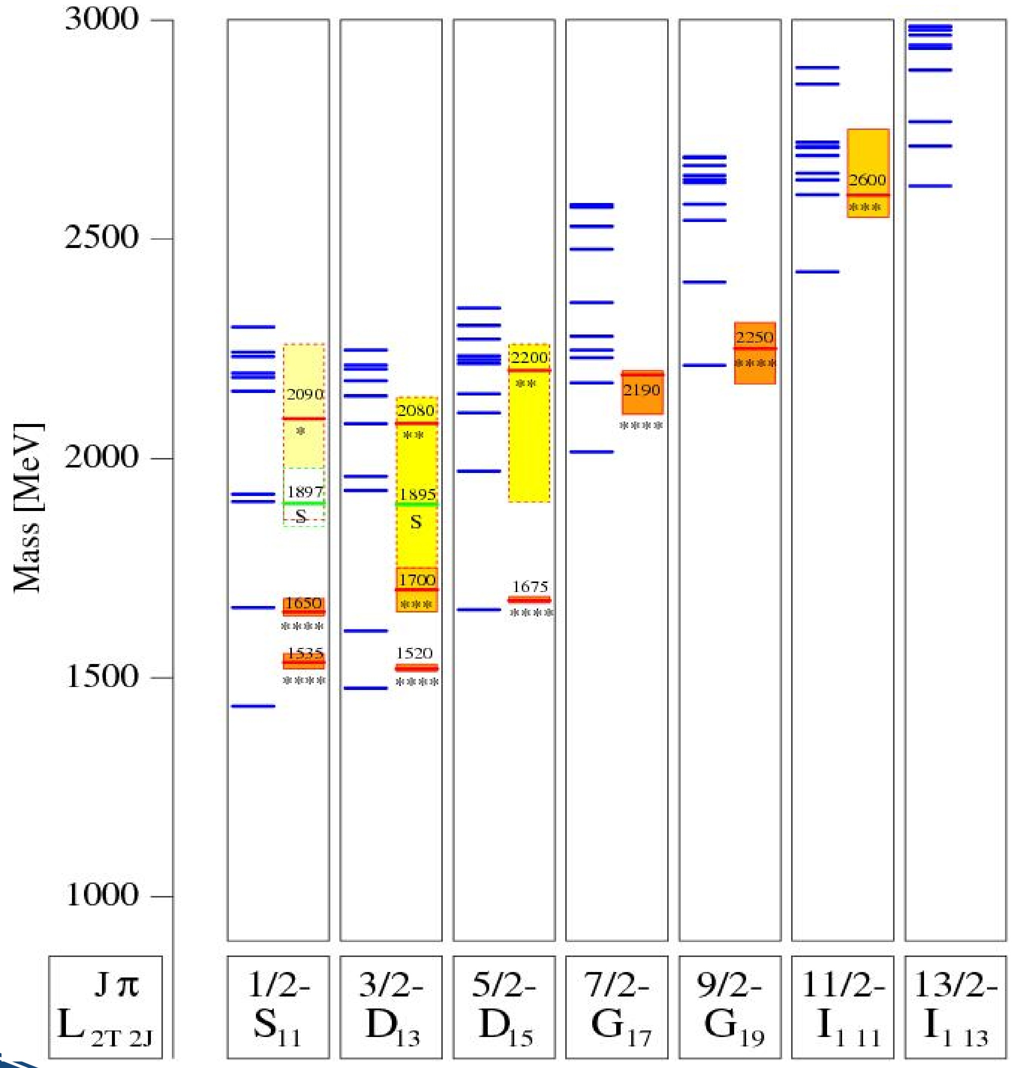
General motivation

- This is an overview of the work done in the last 10 years on electromagnetically induced kaon production and related subjects:
  - Photoproduction: $\gamma p \rightarrow K^+\Lambda$, $\gamma p \rightarrow K^+\Sigma^0$, $\gamma p \rightarrow K^0\Sigma^+$
  - Electroproduction: $ep \rightarrow e'K^+\Lambda$, $ep \rightarrow e'K^+\Sigma^0$, $ep \rightarrow e'K^0\Sigma^+$
  - Radiative kaon capture: $K^-p \rightarrow \Lambda\gamma$, $K^-p \rightarrow \Sigma^0\gamma$
- Central objective: how can we relate theoretical/model predictions for 'dynamical' quantities to experimental data in a quantitative way?

Excited QCD: baryon resonances

- The first excited QCD states are the meson and baryon resonances: N*, Δ*, Y*, Ξ*
- Quantitative information on baryon resonances comes mostly from experiments such as pion scattering and pion photoproduction.
- Missing resonance problem: many baryon states are predicted by quark models but are not seen in the experiments.
- Therefore: look at other channels than πN and γN: ππN, ωN, ηN, η'N, KY and hope that missing resonances couple more to these channels.

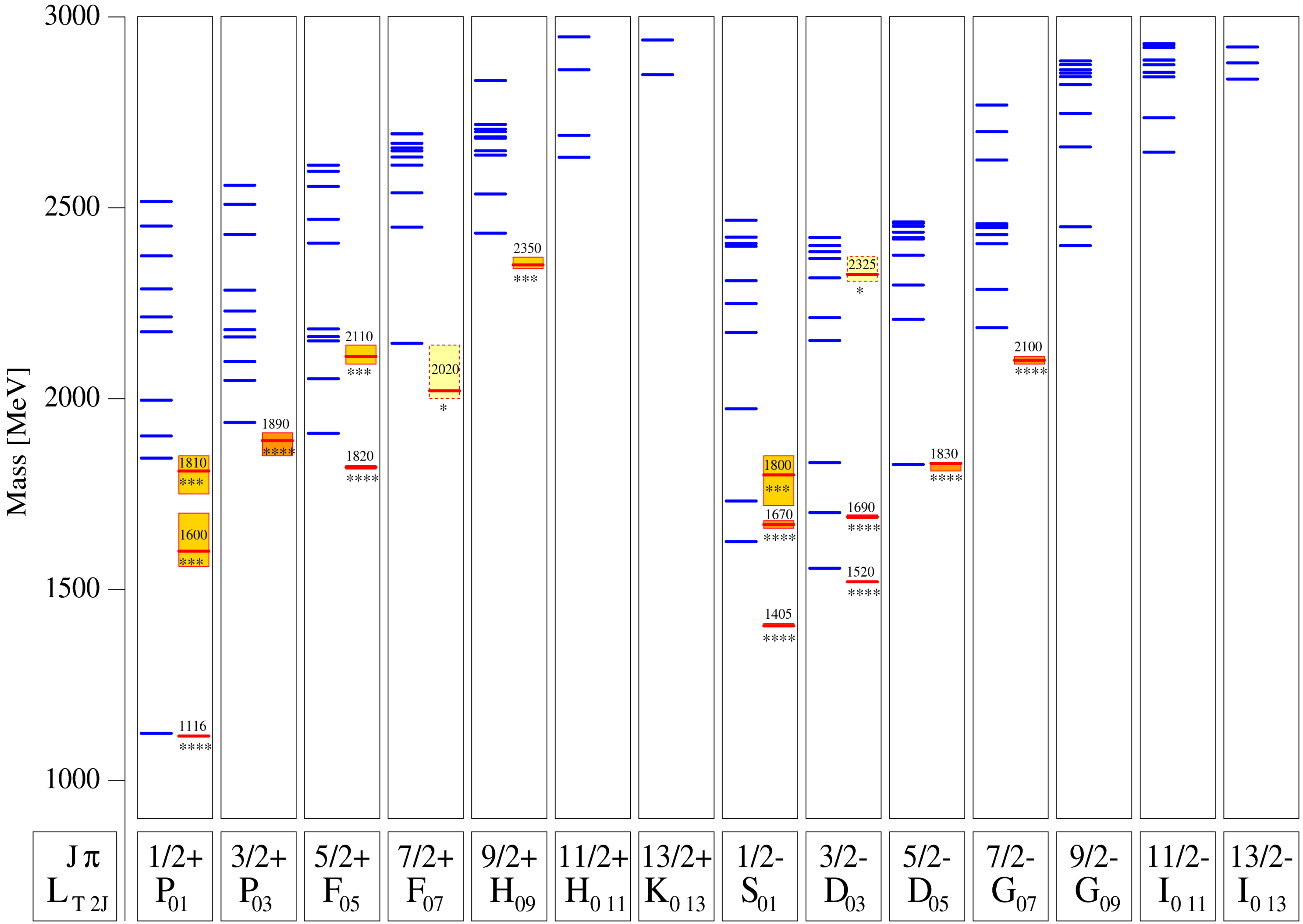
Nucleon resonances (P=-1)



- But: the reaction channels only offer information on nonstrange resonances.

U. Loering, PhD. Thesis, HISKP Bonn, Germany

Hyperon (Λ) resonances



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Radiative kaon capture (S=-1)

- The s-channel resonances in $K^{-}p \rightarrow Y\gamma$ are hyperons (S=-1) and cause resonant structure in observables
- Related to kaon photoproduction through crossing symmetry:

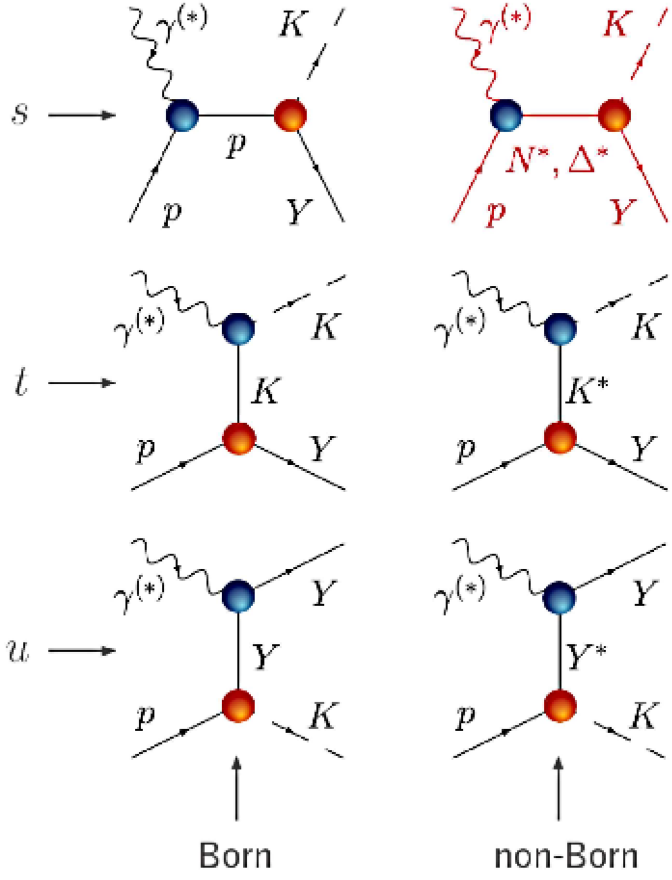
$$M^{Kp\rightarrow Y\gamma}(p,p_K,p_Y,k) = M^{K\text{-}p\rightarrow Y\gamma}(p,-p_K,p_Y,-k)$$

- Difficult reaction to look at experimentally: requires kaon beam:
  - Crystal Ball Collaboration at the AGS-Brookhaven have gathered data for $p_K^{lab} \sim 500 \rightarrow 750$ MeV/c (analysis is on its way).

Unified description of kaon photo- and electroproduction and kaon capture

- We want to give a unified description for the reactions:
  - Photoproduction: $\gamma p \rightarrow K^+\Lambda$, $\gamma p \rightarrow K^+\Sigma^0$, $\gamma p \rightarrow K^0\Sigma^+$
  - Electroproduction: $ep \rightarrow e'K^+\Lambda$, $ep \rightarrow e'K^+\Sigma^0$, $ep \rightarrow e'K^0\Sigma^+$
  - Radiative kaon capture: $K^-p \rightarrow \Lambda\gamma$, $K^-p \rightarrow \Sigma^0\gamma$
- And do this for as large an energy region as possible
- With as few parameters as possible
- First attempt: tree-level isobar model (2000-2004)
- Second attempt: Regge-plus-Resonance (RPR) model

Isobar model for kaon production

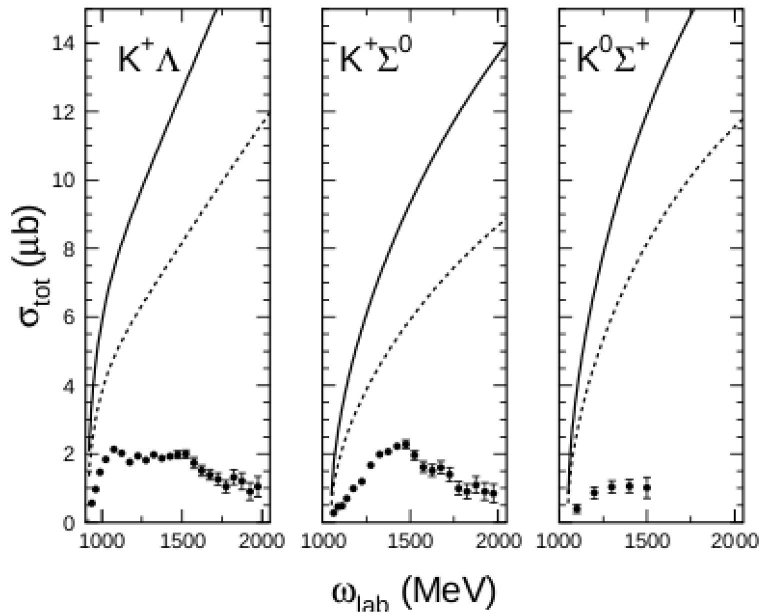


Born terms, t- and u-channel resonance terms give rise to smooth curves; intermediate particle is never on-shell: BACKGROUND CONTRIBUTIONS

Only s-channel resonances can cause structures in kaon production observables: N* and Δ*: RESONANT CONTRIBUTIONS

Isobar model: background problem

- The Born terms alone produce too much strength
- Several possible prescriptions to reduce the Born strength were tried:
  - A: hard strong form factors
  - B: hyperon resonances
  - C: forget SU(3) totally



- Using crossing symmetry, the background models could be tested: only model A gave reasonable results (order of magnitude)

Problems with background remain

- Model A: strong form factor with cutoff ~600 MeV: most physics is hidden in the form factor
- Bad behaviour for large energies
- Extracted resonance parameters (especially coupling constants) are strongly dependent on the model details:
  - Fitting ~20 parameters is not a trivial task
  - Many different local minima are found for χ^2
  - Some resonance's coupling constants are robust, others are not

→ Regge-plus-Resonance (RPR) model

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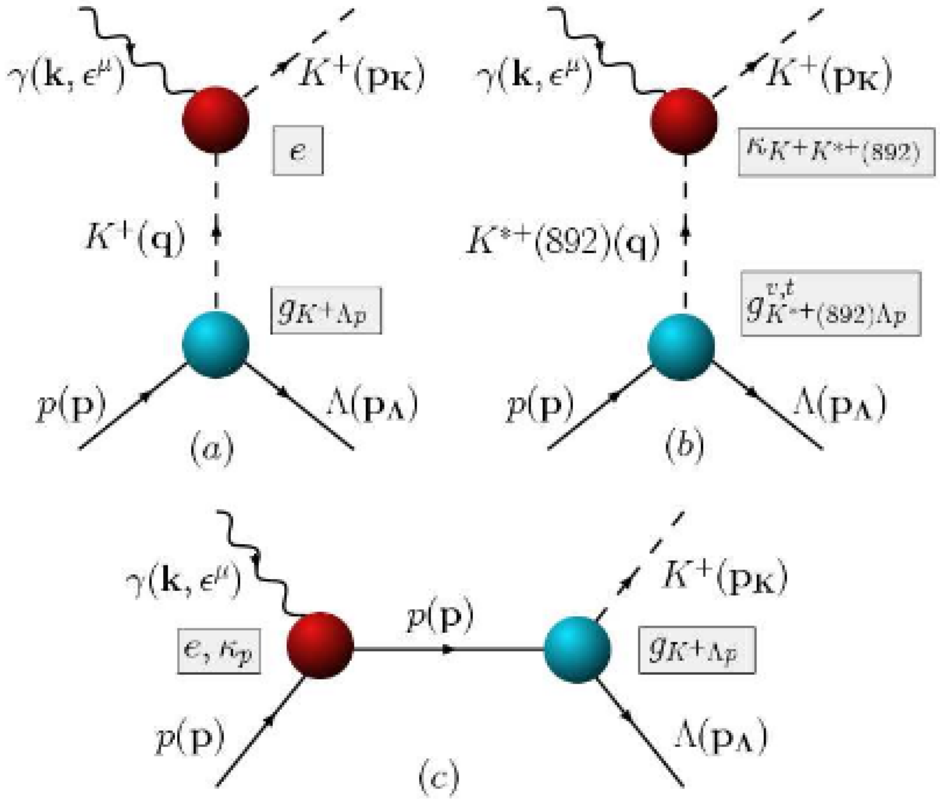
RPR model: background

Background:
t-channel Reggeization



Mathematically:
change the Feynman propagator by the Regge propagator

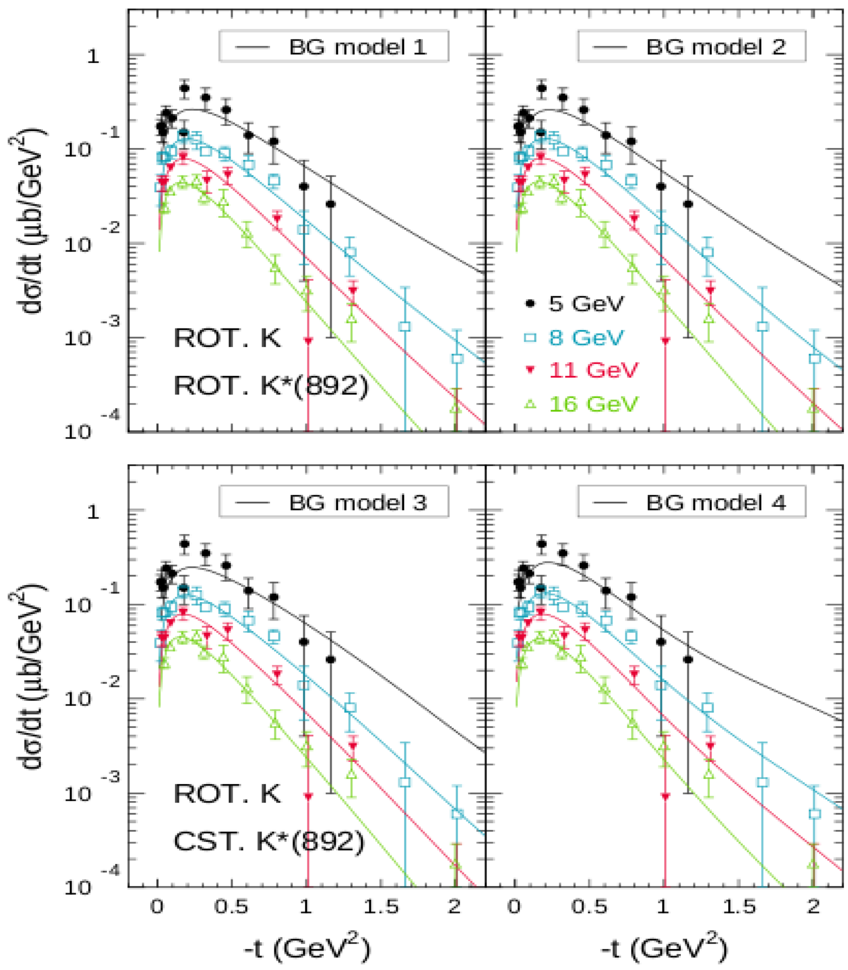
$$\mathcal{P}^{K^+}_{\mathrm{Regge}}(s,t) = \left(\frac{s}{s_0}\right)^{\alpha_{K^+}(t)} \frac{1}{\sin(\pi\alpha_{K^+}(t))} \times \begin{Bmatrix} 1 \\ e^{-i\pi\alpha_{K^+}(t)} \end{Bmatrix} \frac{\pi\alpha'_{K^+}}{\Gamma(1+\alpha_{K^+}(t))},$$

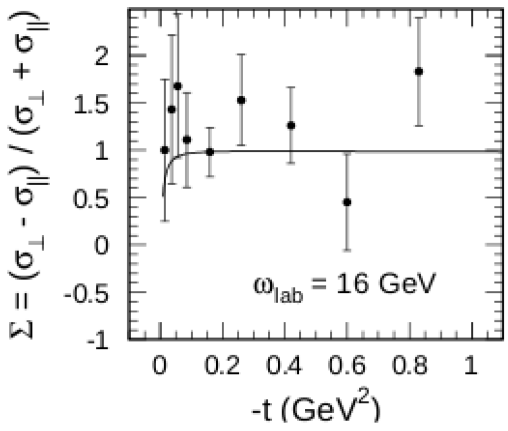
$$\mathcal{P}^{K^{*+}(892)}_{\mathrm{Regge}}(s,t) = \left(\frac{s}{s_0}\right)^{\alpha_{K^{*+}(892)}(t)-1} \frac{1}{\sin(\pi(\alpha_{K^{*+}(892)}(t)-1))} \begin{Bmatrix} 1 \\ e^{-i\pi(\alpha_{K^{*+}(892)}(t)-1)} \end{Bmatrix} \frac{\pi\alpha'_{K^{*+}(892)}}{\Gamma(\alpha_{K^{*+}(892)}(t))},$$

RPR model

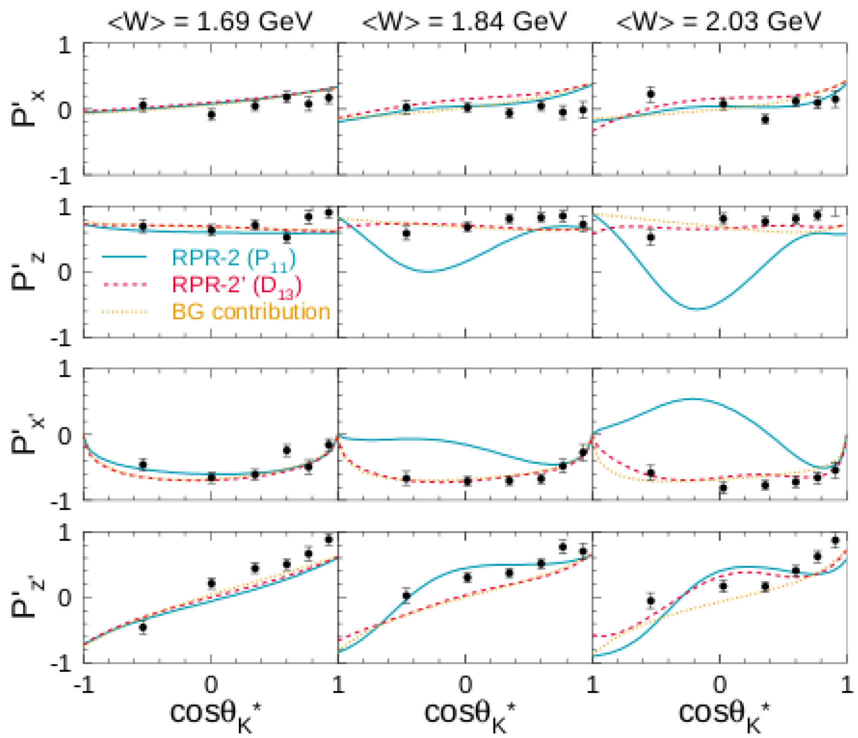
- Only three parameters for the background
- No strong form factors
- Has the correct high energy behaviour! Therefore, the three background parameters can be fitted to high-energy data, where resonances are not expected to do much
- Once the background parameters are fitted to high-energy data, we can take the background prescription to the resonance region and add a limited number of s-channel resonances (problem of double counting) to account for the structure in kaon production observables

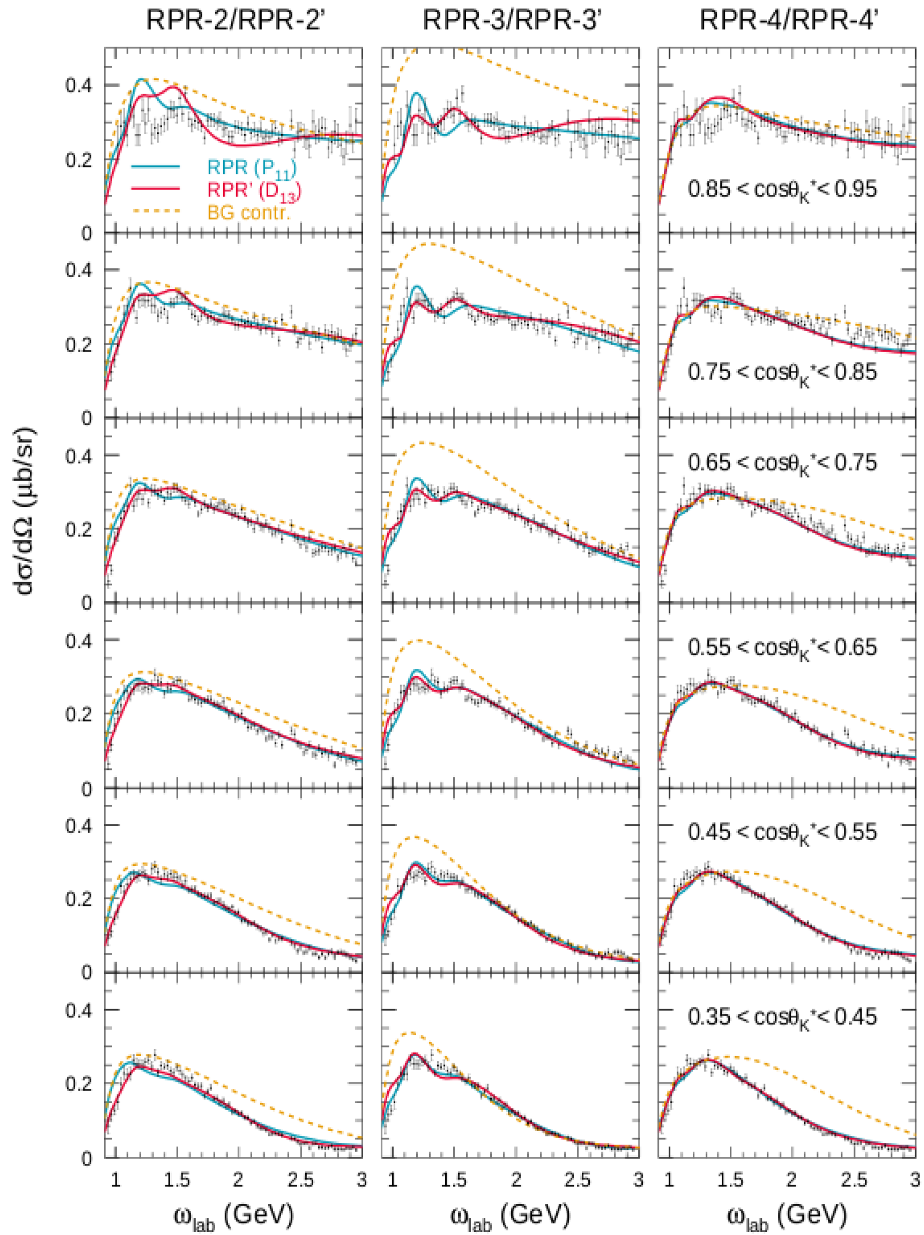
RPR: background results (high energy)





Some results for the RPR





Core set of resonances: $S_{11}(1650)$, $P_{11}(1710)$, $P_{13}(1720)$
Extra resonances: $P_{13}(1900)$ (PDG), $D_{13}(1900)$, $P_{11}(1900)$ (missing)

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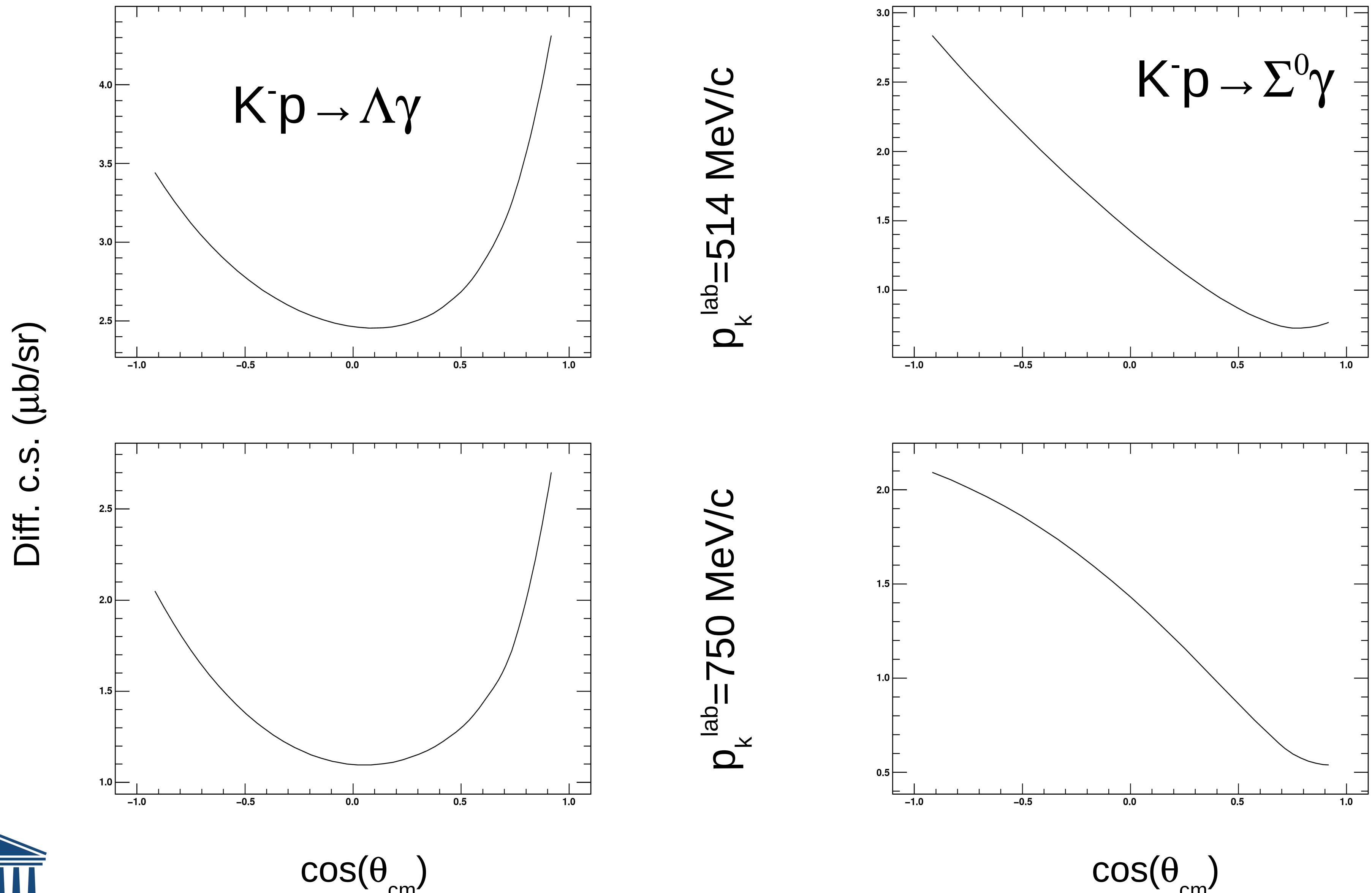
RPR for kaon capture (background)



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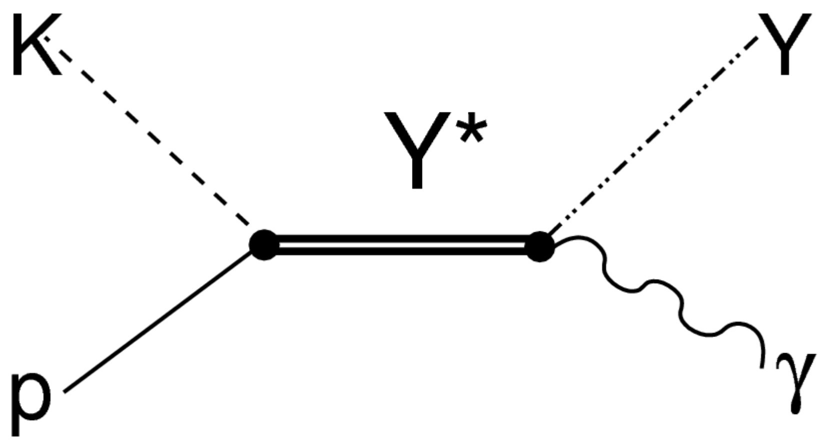
Hyperon resonances (in progress)



- Y*'s can be introduced in the s-channel of kaon capture to account for possible structure
- Fitting the Y*'s coupling constants to the data leads to information on the product of strong and EM coupling

- Compare the different isospin channels $K^-p \rightarrow \Lambda\gamma$ and $K^-p \rightarrow \Sigma^0\gamma$ to get the EM coupling constant
- EM coupling constants can be computed in quark models: predictive value is tested!

EM couplings for Y*'s

- The CB collaboration have measured the kaon capture process for kaon-labmomenta from ~500 tot 750 MeV/c. This means they have probed invariant masses from ~1560 to 1680 MeV
- PDG gives four Y*'s in this energy reason: P_{01}(1600), S_{01}(1670), P_{11}(1660), D_{13}(1670); and another three nearby: S_{01}(1405), D_{03}(1520), D_{03}(1690)
- All these resonances can be tested seperately and in combinations. Comparison between the two isospin channels will lead to ratio's of EM coupling constants, which can be compared to quark model predictions

Conclusions and outlook

- Unifying model for kaon photoproduction at high and intermediate energies, for kaon electroproduction, and for the crossing-symmetry related radiative kaon capture process
- Background is fitted to high energy data: parameter-poor background description
- Kaon photo- and electroproduction observables are well to very well described
- Reggeized background seems to work very well for radiative kaon capture. This offers a rather clear way of extracting coupling constants for hyperon resonances from the experiments

Photoproduction data

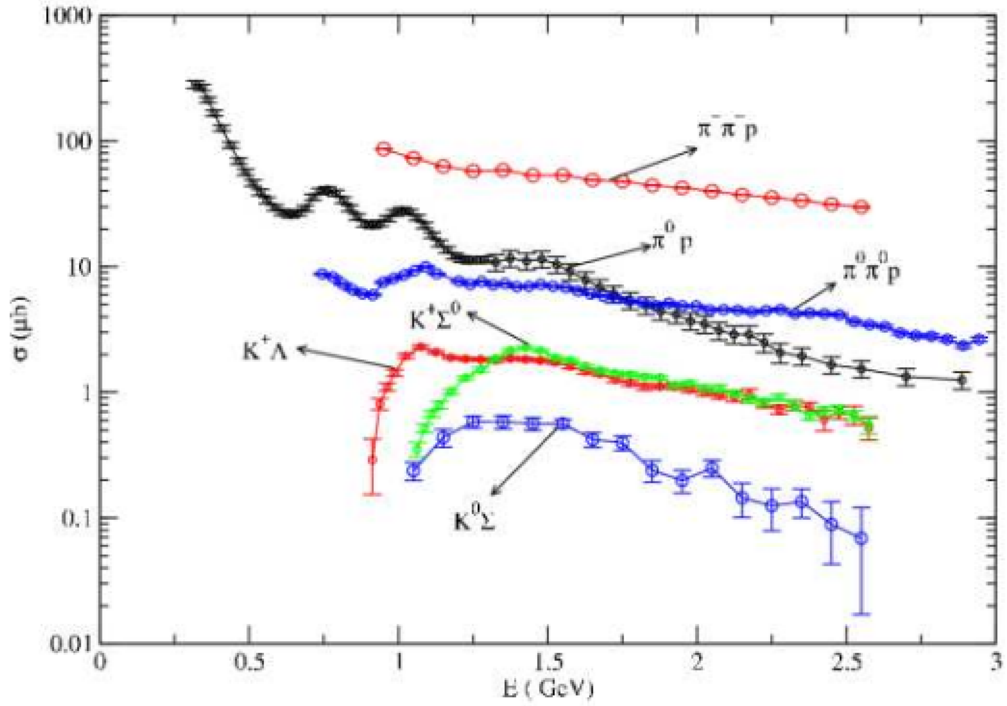


Figure 2.1 Dominant contributions making up the total cross section for photoproduction from a free proton [47]. Data for one- and two-meson final states are displayed.

[47] http://ebac-theory.jlab.org/papers.htm.

Regge trajectories