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FACULTY OF SCIENCES

Regge-plus-resonance predictions for kaon photoproduction from the deuteron

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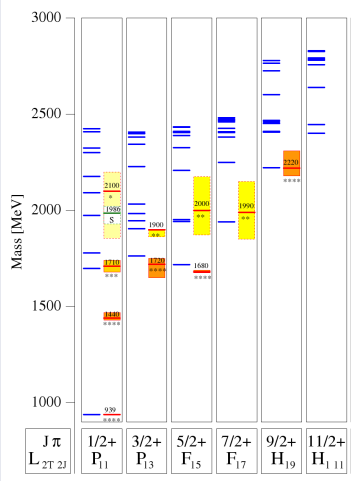
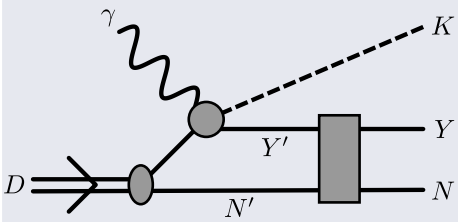
Kaon production from the deuteron

Why?



- Extract the $n(\gamma, K)Y$ amplitude: complementary information to establish nucleon spectrum
- Investigate nuclear-medium effects
- Study hyperon-nucleon potential
  - hypernuclear spectroscopy
  - final-state interactions in $^2\mathrm{H}(\gamma, KY)N$

How?



- Elementary-production operator: RPR model
  - Describe $K^+\Lambda$ and $K^+\Sigma^0$ channels
  - Predictive power in other channels
- *Dnp*-vertex: relativistic
- Ignore FSI: focus on semi-inclusive kaon production

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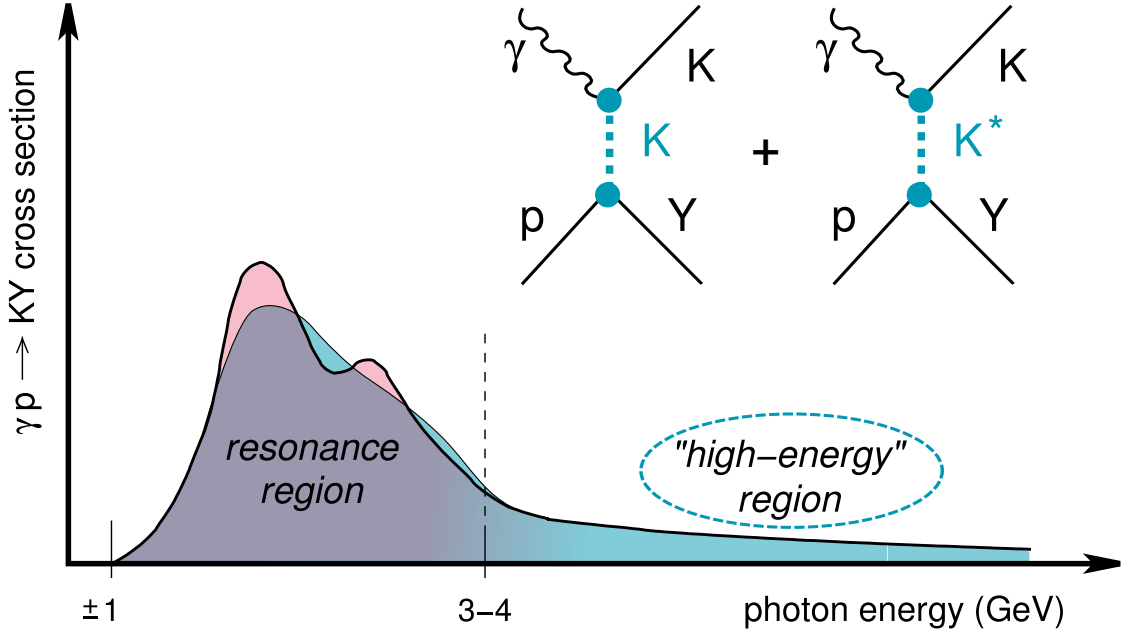
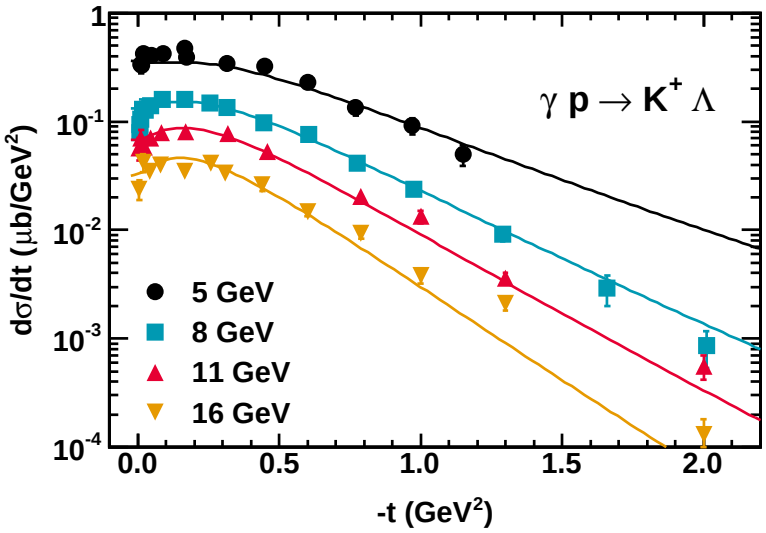
The Regge-plus-resonance model (I)

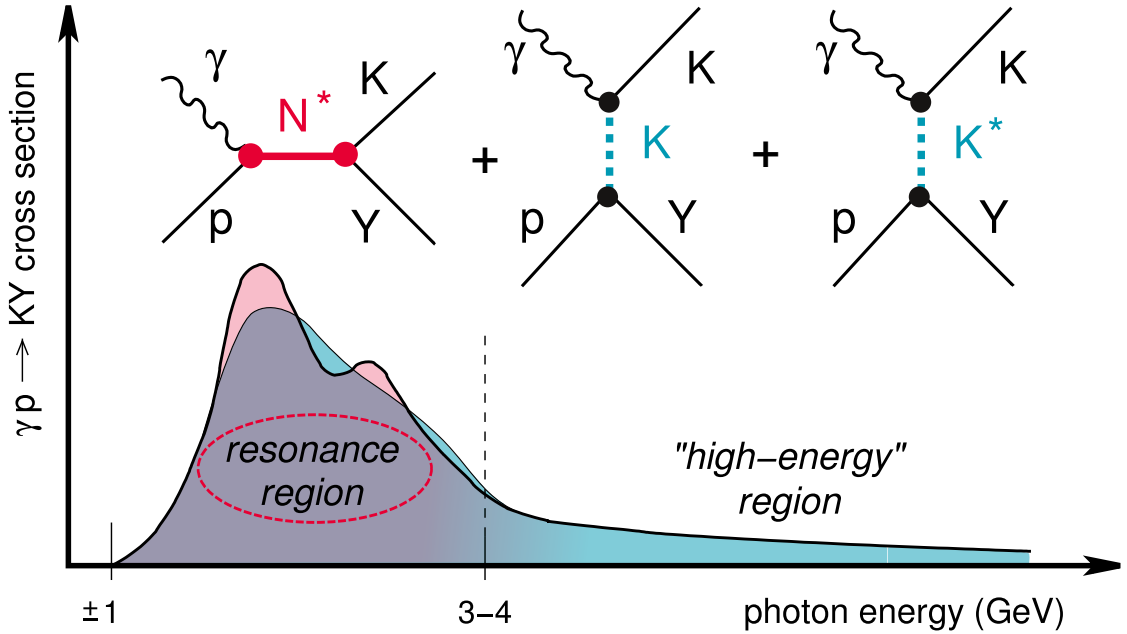


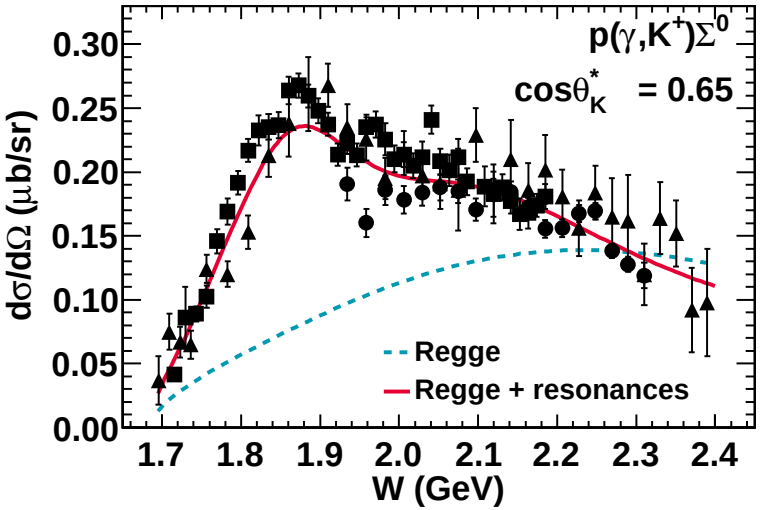


Background contributions NPA627(1997)645

- Exchange of $K(494)$ and $K^*(892)$ Regge trajectories in t channel
- Valid for $s \gg$ and forward angles
- Describes gross features of data in the resonance region (duality)

The Regge-plus-resonance model (II)





Resonant contributions

- enrich Regge background with nucleon and delta resonances
- standard Feynman s-channel diagrams
- EM form factors from Bonn CQM

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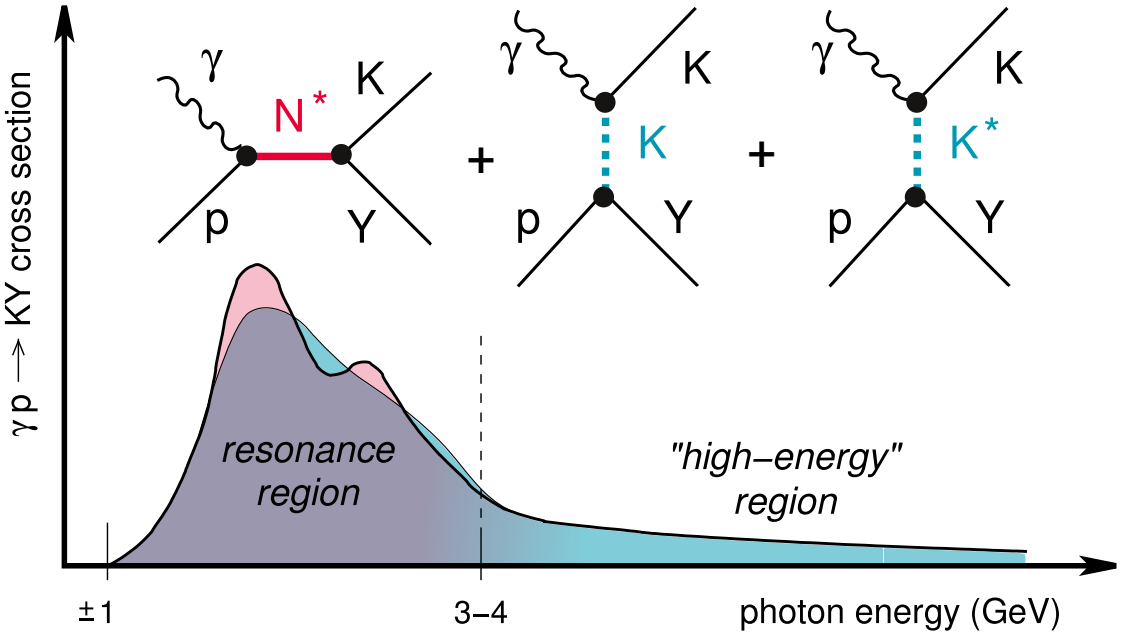
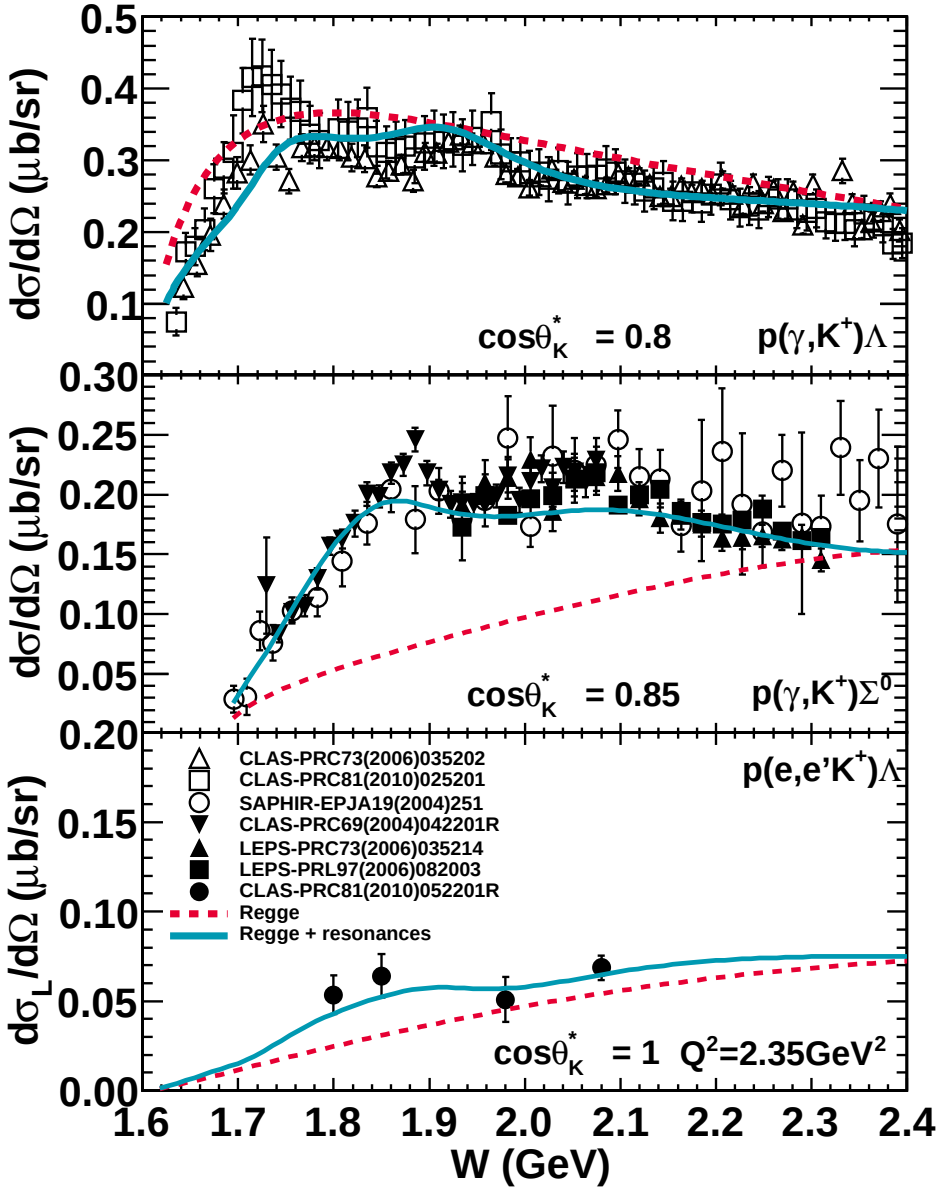
The Regge-plus-resonance model (III)



The RPR strategy

1. Construct Regge model for high-energy (=background) amplitude, and fit parameters to the available high-energy data.
2. Add resonance contributions (N^* and/or Δ^*) to obtain the full RPR amplitude, and fit parameters to the resonance region data.

Regge-plus-resonance results



$K^+\Lambda$ channel PRC73(2006)045207

- $K(494)$- and $K^*(892)$-trajectories
- $S_{11}(1650)$, $P_{11}(1710)$, $P_{13}(1720)$, $P_{13}(1900)$
- *missing* $D_{13}(1900)$

$K^+\Sigma^0$ channel PRC75(2007)045204

- $K(494)$- and $K^*(892)$-trajectories
- $S_{11}(1650)$, $P_{11}(1710)$, $P_{13}(1720)$, $P_{13}(1900)$
- $D_{33}(1700)$, $S_{31}(1900)$, $P_{31}(1910)$, $P_{33}(1920)$

Electroproduction PLB656(2007)186

EM form factors from Bonn CQM

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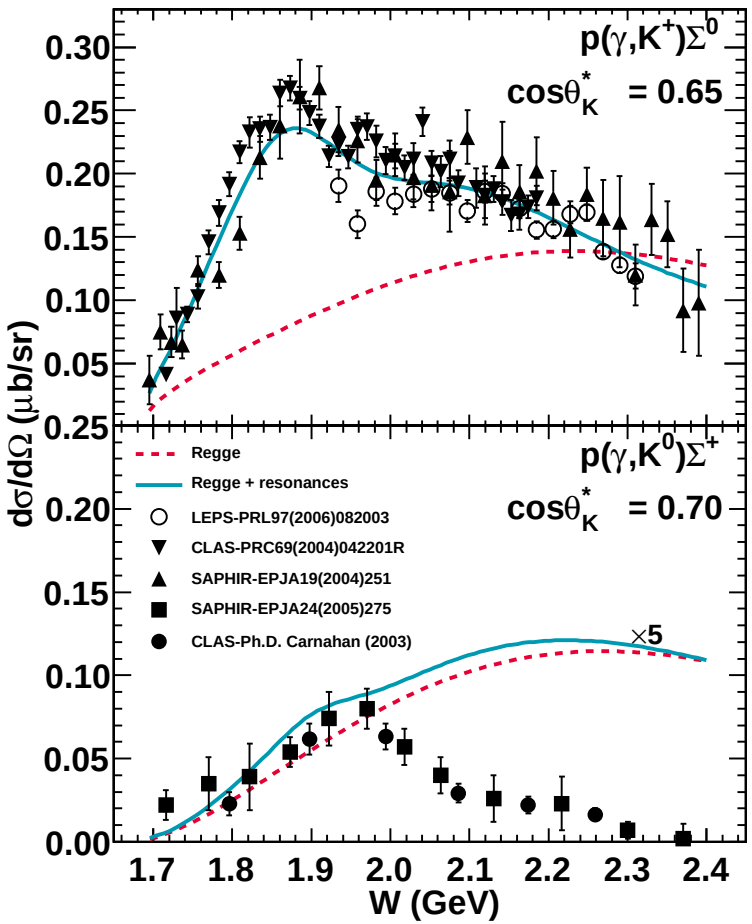
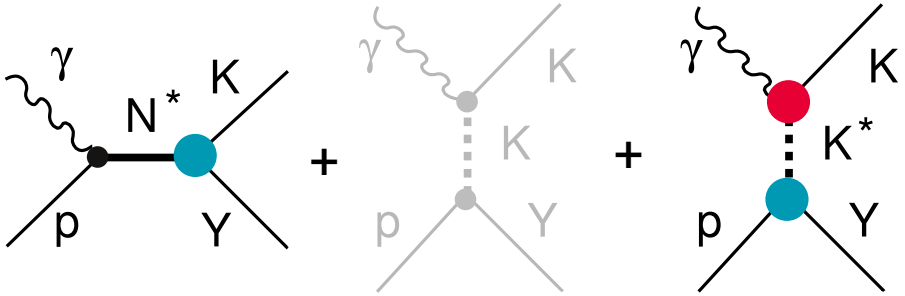
Neutral-kaon production (I)



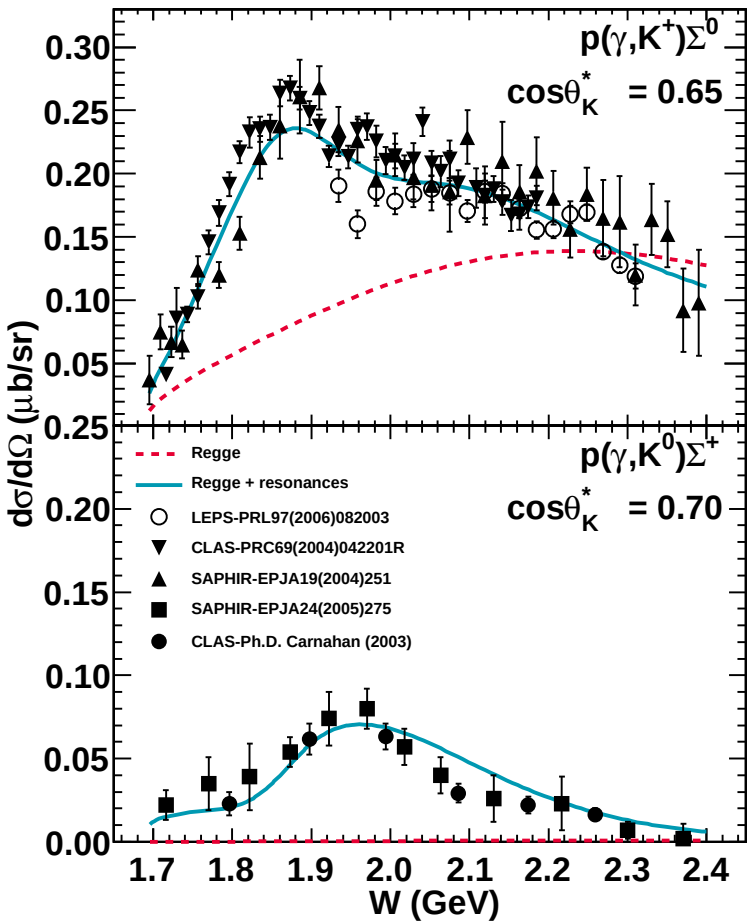
$p(\gamma, K^+)\Sigma^0 \longrightarrow p(\gamma, K^0)\Sigma^+$

- $K(494)$-exchange vanishes
- isospin relations at strong vertex
  $g_{K^{(*)0}\Sigma^+ N^{(*)}} = \sqrt{2} g_{K^{(*)+}\Sigma^0 N^{(*)}}$
- ratio of EM decay widths at EM vertex
  $\frac{\kappa_{K^{*0}(892)K^0(494)}}{\kappa_{K^{*+}(892)K^+(494)}} = -1.53 \pm 0.10$

The cross section is overpredicted by an order of magnitude!



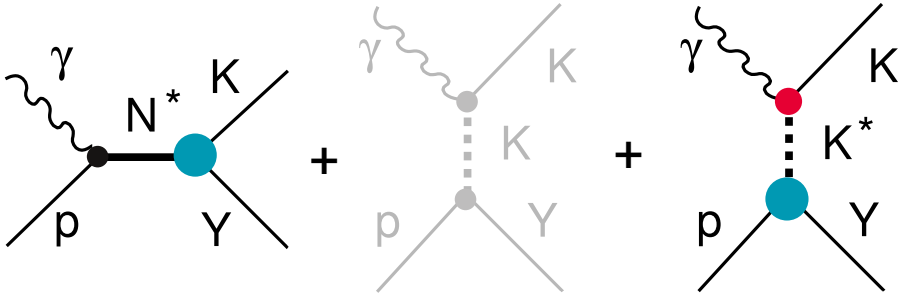
Neutral-kaon production (II)



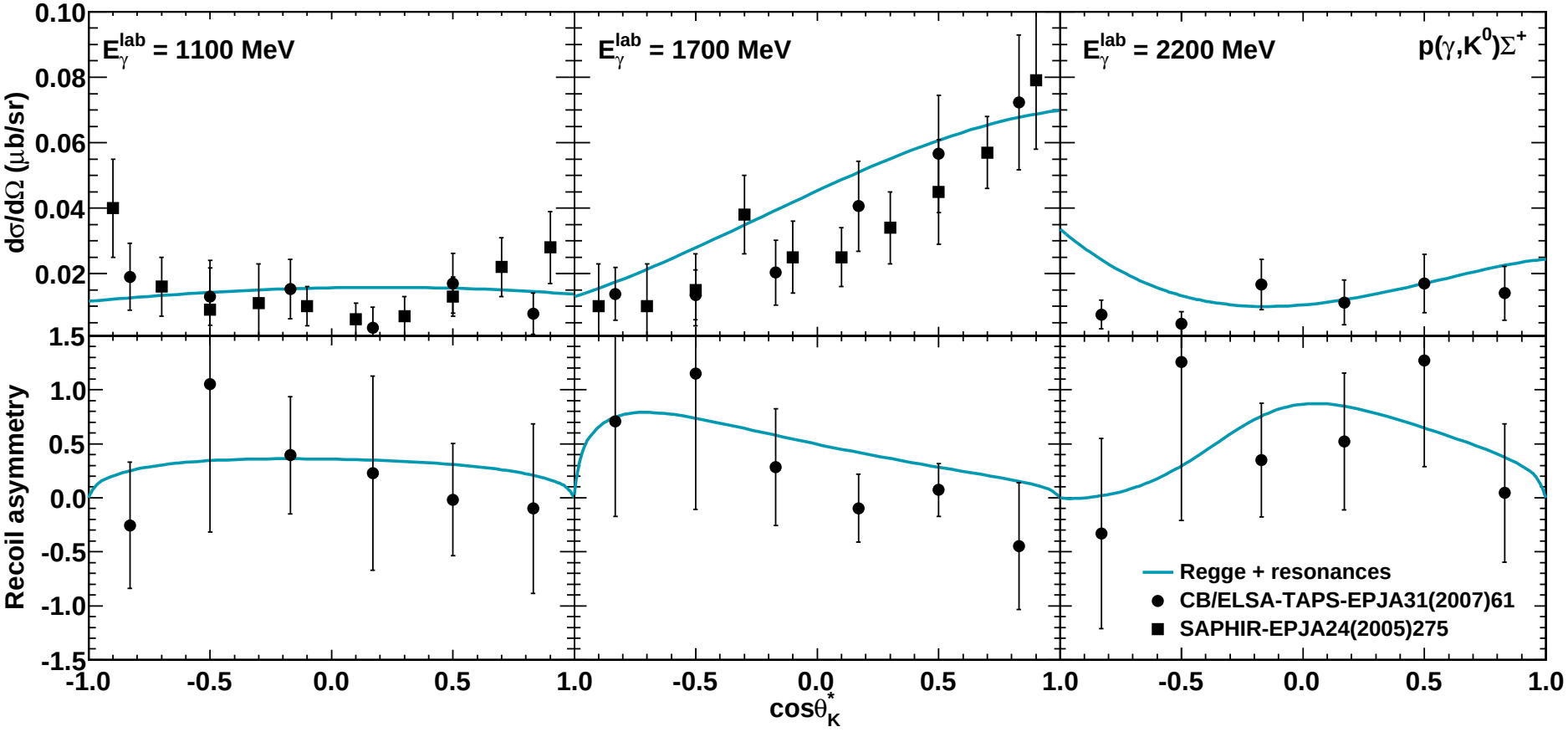
$p(\gamma, K^+)\Sigma^0 \longrightarrow p(\gamma, K^0)\Sigma^+$

- $K(494)$-exchange vanishes
- isospin relations at strong vertex
  $g_{K^{(*)0}\Sigma^+ N^{(*)}} = \sqrt{2} g_{K^{(*)+}\Sigma^0 N^{(*)}}$
- Fit ratio of EM coupling constants to available $K^0\Sigma^+$ data
  $\frac{\kappa_{K^{*0}(892)K^0(494)}}{\kappa_{K^{*+}(892)K^+(494)}} = 0.05 \pm 0.01$

Nice description of data ($\chi^2/n.d.f. = 3.4$).



Neutral-kaon production (III)



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Kaon production from the free neutron (I)

Resonance		SAID PRC53(1996)430
$S_{11}(1650)$	$\frac{\kappa_{N^*n}}{\kappa_{N^*p}}$	-0.22 ± 0.07
$P_{11}(1710)$	$\frac{\kappa_{N^*n}}{\kappa_{N^*p}}$	-0.29 ± 2.23
$P_{13}(1720)$	$\frac{\kappa^{(1)}_{N^*n}}{\kappa^{(1)}_{N^*p}}$	-0.38 ± 2.00
	$\frac{\kappa^{(2)}_{N^*n}}{\kappa^{(2)}_{N^*p}}$	-0.50 ± 1.08
		Unknown
$P_{13}(1900)$	$\frac{\kappa^{(1)}_{N^*n}}{\kappa^{(1)}_{N^*p}}$	0.00 ± 2.00
	$\frac{\kappa^{(2)}_{N^*n}}{\kappa^{(2)}_{N^*p}}$	0.00 ± 2.00

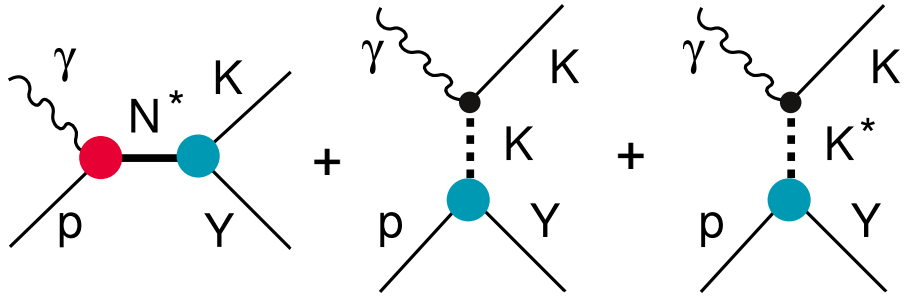
$p(\gamma, K^+)\Sigma^0 \longrightarrow n(\gamma, K^+)\Sigma^-$

- isospin relations at strong vertex

$$g_{K^{(*)+}\Sigma^- N^{(*)0}} = \sqrt{2}\, g_{K^{(*)+}\Sigma^0 N^{(*)+}}$$
$$\sqrt{2}\, g_{K^+\Sigma^-\Delta^{*0}} = g_{K^+\Sigma^0\Delta^{*+}}$$

- ratio of helicity amplitudes at EM vertex

$$\frac{\kappa_{nN^*}}{\kappa_{pN^*}} = \frac{\mathcal{A}^n_{1/2}}{\mathcal{A}^p_{1/2}}, \ldots$$



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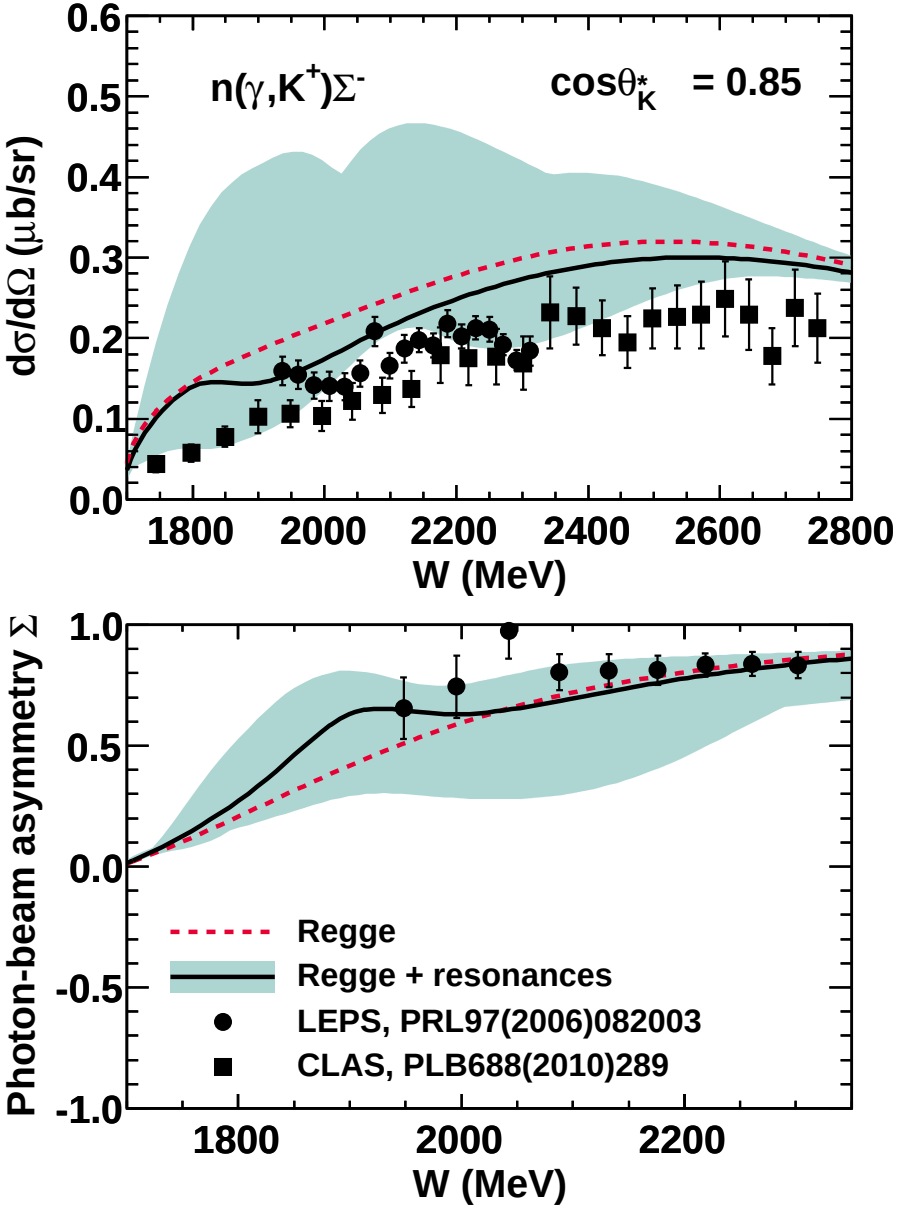
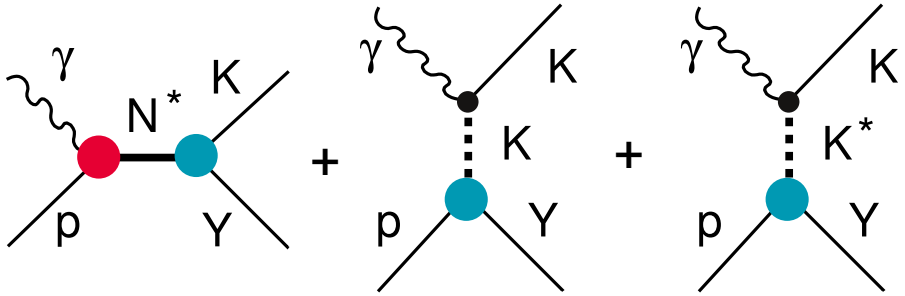
Kaon production from the free neutron (II)



$p(\gamma, K^+)\Sigma^0 \longrightarrow n(\gamma, K^+)\Sigma^-$

- isospin relations at strong vertex
- ratio of helicity amplitudes at EM vertex

Uncertainty N^* helicity amplitudes restrains the predictive power of the RPR model PLB681(2009)428



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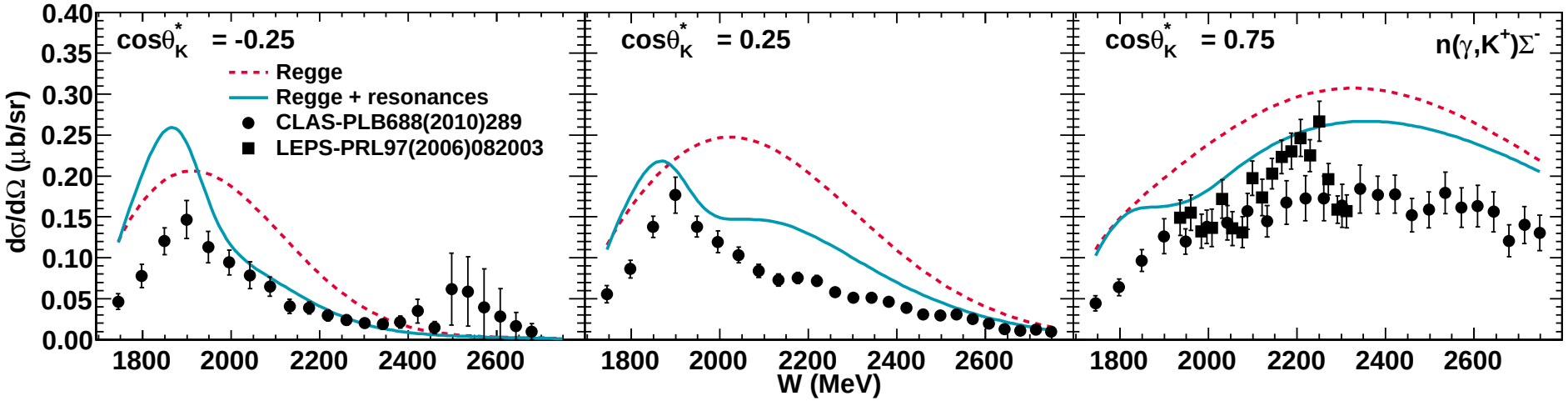
Kaon production from the free neutron (III)



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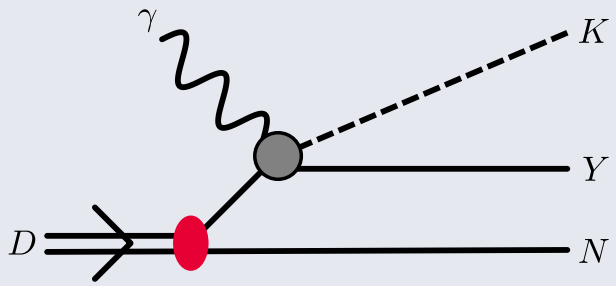
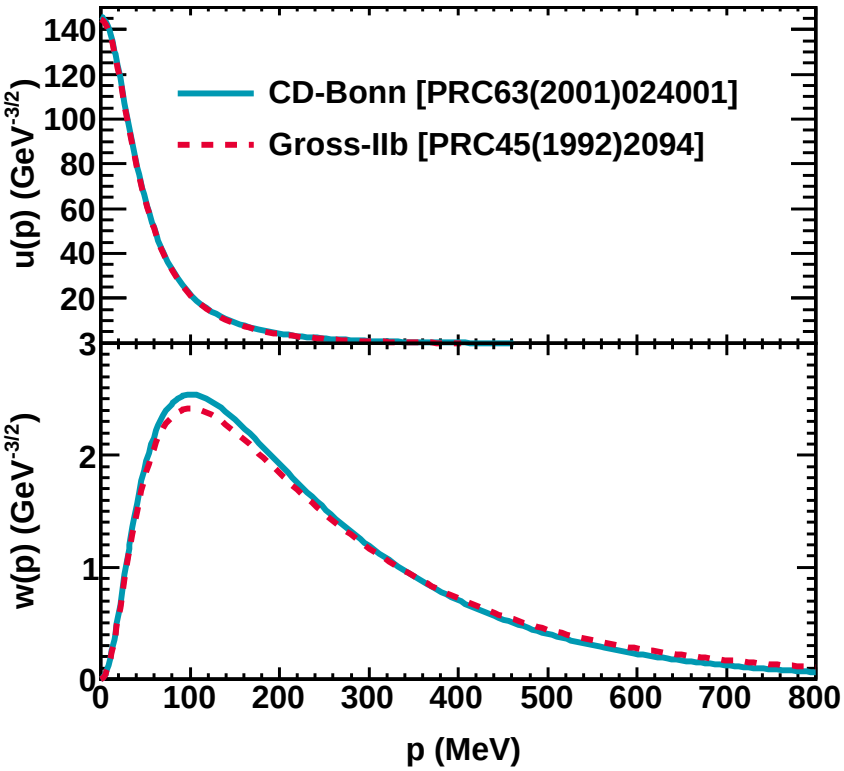
Kaon production from the deuteron: formalism (I)

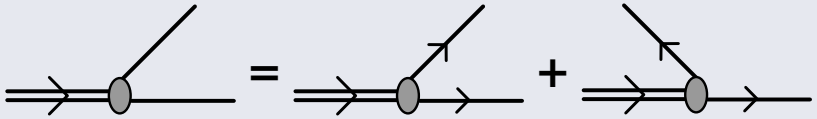
Plane-wave impulse approximation



$$= \bar{u}_Y \, \Gamma^{\lambda_\gamma}_{\text{RPR}} \, \frac{m_N + \not{p}_{N'}}{m_N^2 - p_{N'}^2} \, \Gamma^{\lambda_D}_{\text{BC}} \, \mathcal{C} \bar{u}_N^T$$



Relativistic *Dnp*-vertex



- Positive-energy part
  - $L = 0$ and $L = 2$ wave functions
  - Realistic *NN*-potential, e.g. CD-Bonn
- Negative-energy part
  - $L = 1$ wave functions
  - Relativistic Gross formalism

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Kaon production from the deuteron: formalism (I)

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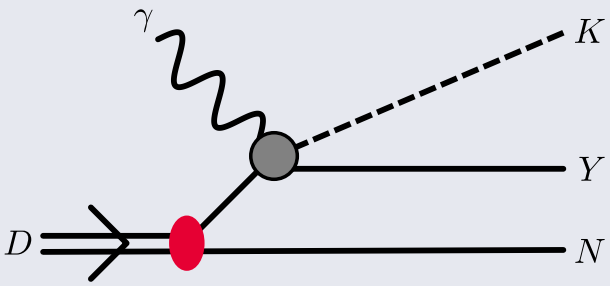
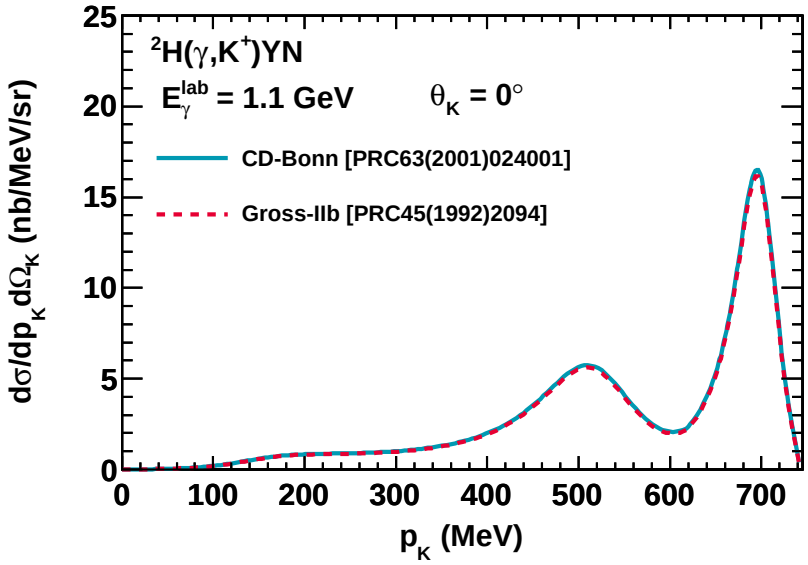


$$= \bar{u}_Y \, \Gamma^{\lambda_\gamma}_{\text{RPR}} \, \frac{m_N + \not{p}_{N'}}{m_N^2 - p_{N'}^2} \, \Gamma^{\lambda_D}_{\text{BC}} \, \mathcal{C} \bar{u}_N^T$$



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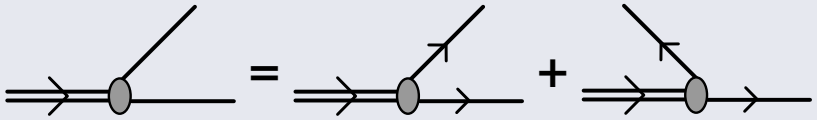

- Positive-energy part
  - $L = 0$ and $L = 2$ wave functions
  - Realistic *NN*-potential, e.g. CD-Bonn
- Negative-energy part
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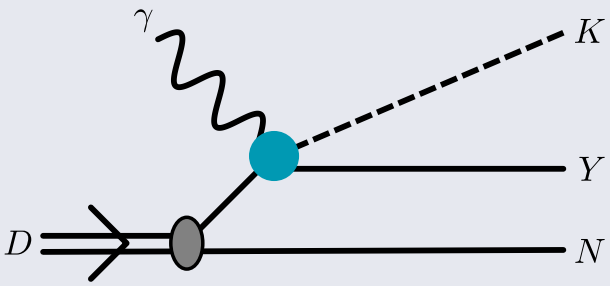
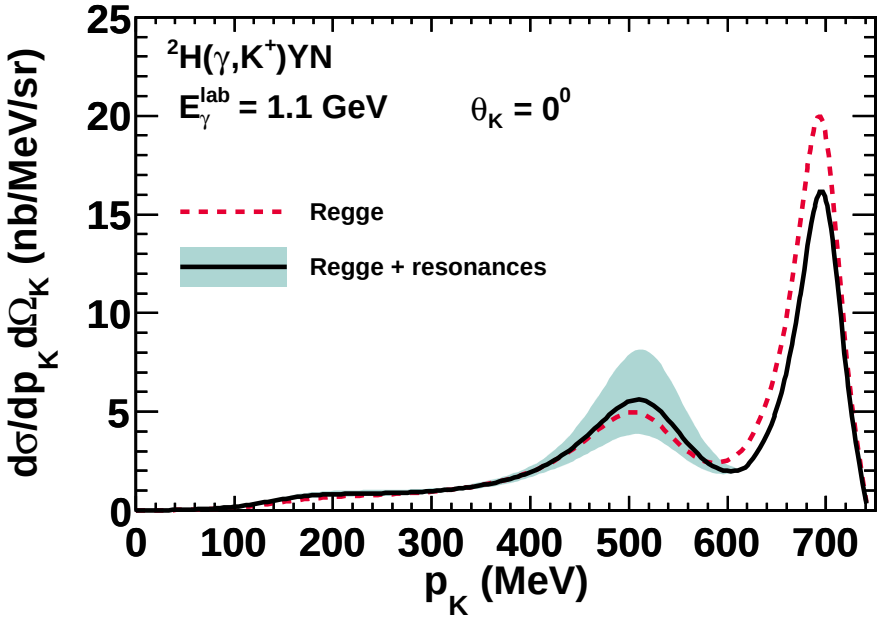
Kaon production from the deuteron: formalism (II)

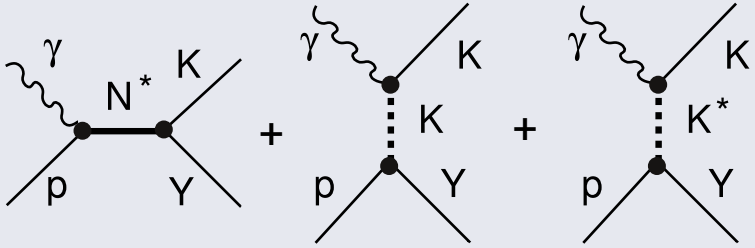
Plane-wave impulse approximation



$$= \bar{u}_Y \, \Gamma^{\lambda_\gamma}_{\text{RPR}} \, \frac{m_N + \not{p}_{N'}}{m_N^2 - p_{N'}^2} \, \Gamma^{\lambda_D}_{\text{BC}} \, \mathcal{C} \bar{u}_N^T$$

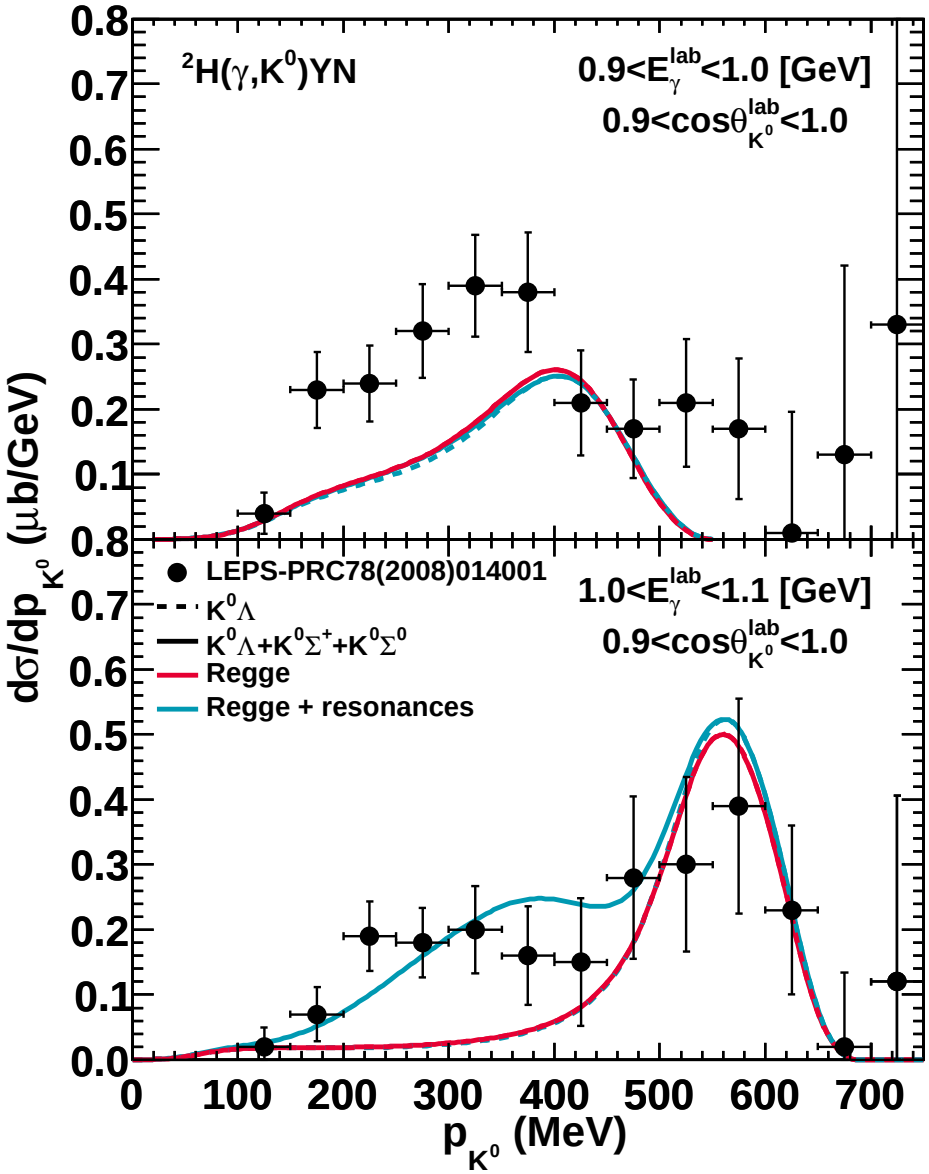


Elementary-production operator



- Semi-inclusive K^+ production $= K^+\Lambda + K^+\Sigma^0 + K^+\Sigma^-$
- Uncertainties N^* helicity amplitudes propagate!

Neutral-kaon production from the deuteron



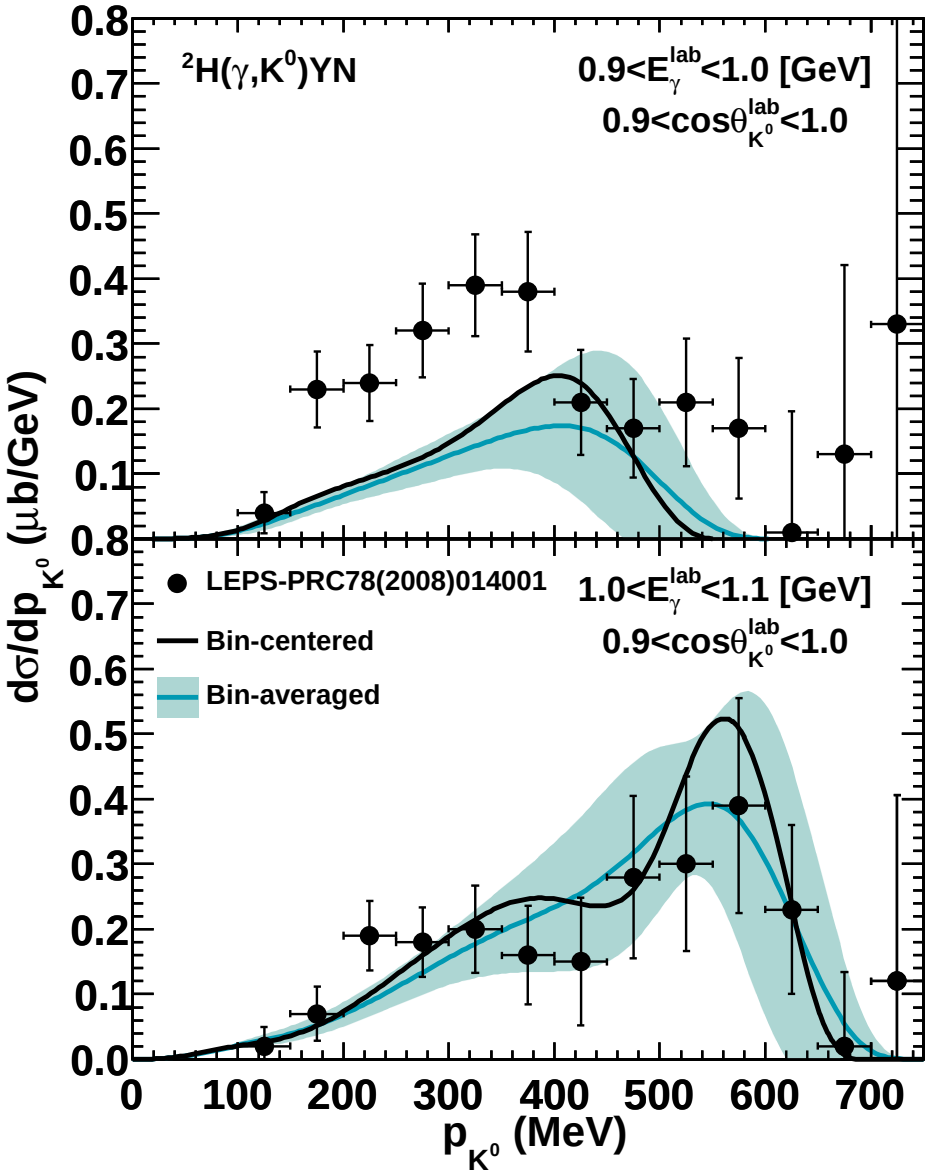
LEPS dataset PRC78(2008)014001

- Semi-inclusive K^0 production $= K^0\Lambda + K^0\Sigma^0 + K^0\Sigma^+$
- Only forward angles $\frac{d\sigma}{dp_K} = 2\pi \int_{0.9}^{1.0} \frac{d\sigma}{dp_K\, d\Omega_K} d\cos\theta_K$

RPR predictions

- $\langle E_\gamma^{lab} \rangle = 950$ MeV
  - below $K^0\Sigma$ threshold
  - data is underpredicted
- $\langle E_\gamma^{lab} \rangle = 1050$ MeV
  - 2 quasi-elastic peaks
  - good predictions

Neutral-kaon production from the deuteron



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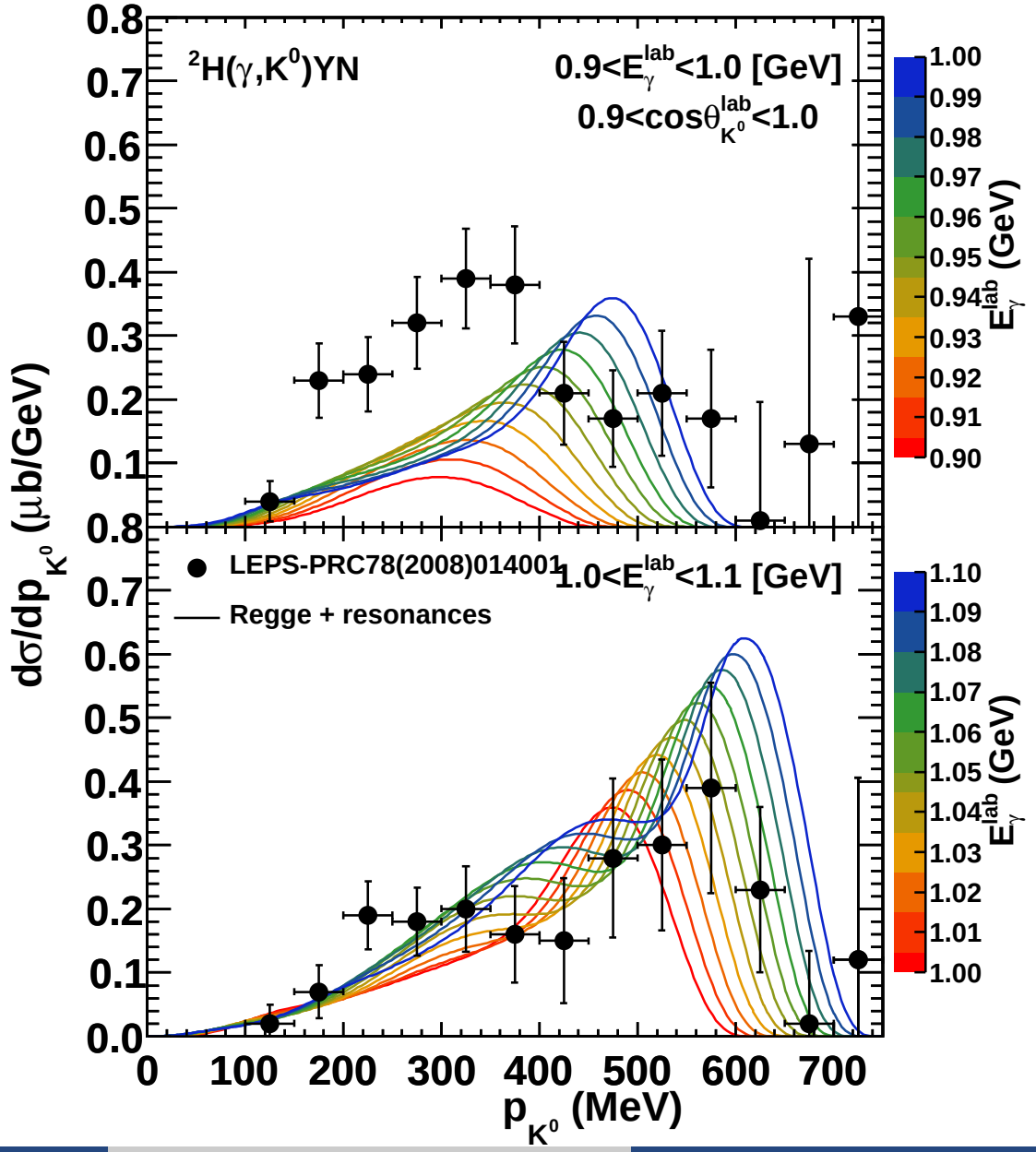
Conclusions

- Regge-plus-resonance (RPR) approach
  - fixes Regge background at **high energies**
  - adds N^*'s and Δ^*'s in the **resonance region**
- Kaon production on free nucleon
  - threshold $\leq E_\gamma^{lab} \leq 16\,\text{GeV}$
  - economical description of $K^+\Lambda$ and $K^+\Sigma^0$ channels
  - **predictive power**
    - K^0 production
    - K production from the neutron
- Kaon production on deuteron
  - *Dnp*-vertex is under control
  - elementary-production operator dominates (helicity amplitudes!)
  - Good predictions for semi-inclusive K^0 production data

Extra

Neutral-kaon production from the deuteron



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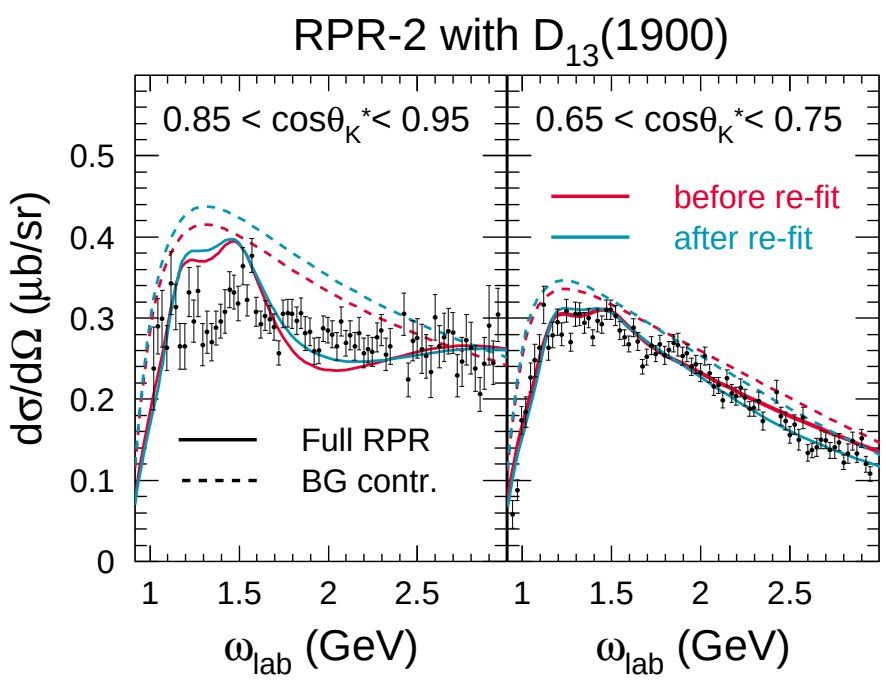
The issue of double counting...



Phys. Lett. **B656**, 186 (2007)

Duality

energy-averaged sum over all N^*'s equals the sum over all t-channel Regge-trajectory echanges

Evaluate double counting

- Refit BG and resonances simultaneously
- effect on BG and full RPR is modest
- estimated effect on resonance parameters is 20 %

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