Strangeness photoproduction on quasifree neutrons

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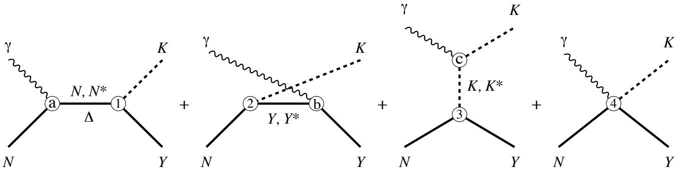
A2

Outline

Strangeness photoproduction



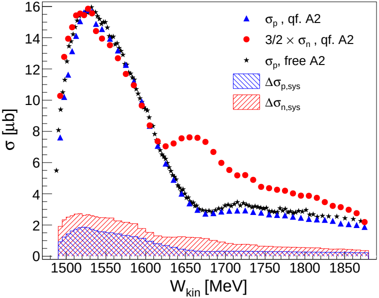
(1) $\gamma p \to K^+\Lambda$
(2) $\gamma p \to K^+\Sigma^0$
(3) $\gamma p \to K^0\Sigma^+$

(4) $\gamma n \to K^0\Lambda$
(5) $\gamma n \to K^0\Sigma^0$
(6) $\gamma n \to K^+\Sigma^-$

- involves $s\bar{s}$ from sea in the nucleon: production mechanisms?
- s-channel contributions? nonstrange resonances ↔ strange hadrons
- only states with $M > \sim 1.7$ GeV are contributing
- missing states with considerable Γ_i to KY?
- $K\Lambda$ isospin filter: only $N(I = 1/2)$ states are present
- hyperon recoil polarization via weak decay
  ⇒ first 'complete' experiment (PS: ≥ 8 obs.) on proton and neutron?

Meson photoproduction on the neutron

- isospin decomposition of electromagnetic transition amplitudes
  $\Rightarrow$ requires neutron measurements
- $N(I = 1/2)$ states have different photocouplings to proton and neutron
- photoexcitation of certain states off the proton suppressed
  $\Rightarrow$ Moorhouse selection rule: γNN^* is zero for $\gamma p \rightarrow [70, {}^48]$ in nonrel. QM
- stronger neutron-coupling expected for members of speculative antidecuplet
- in general sparse experimental database of observables
- full of surprises!
  example: $\gamma n \rightarrow \eta n$
  $\Rightarrow$ peak in σ around $W = 1680$ MeV
  - exotics?
  - $S_{11}(1535)$–$S_{11}(1650)$ interference?
  - $P_{11}(1710)$?
  - coupled-channel effects?

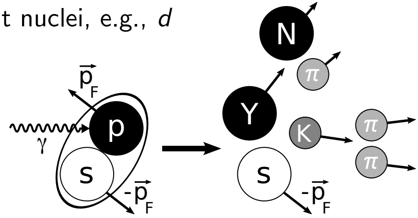


D. Werthmüller et al., Phys. Rev. Lett. 111, 232001 (2013)
D. Werthmüller et al., Phys. Rev. C 90, 015205 (2014)

Strangeness production on quasifree neutrons

Measurement in quasi-free kinematics on light nuclei, e.g., d
⇒ participant (p) - spectator (s) model

$$\gamma + d \rightarrow K + Y + (s)$$

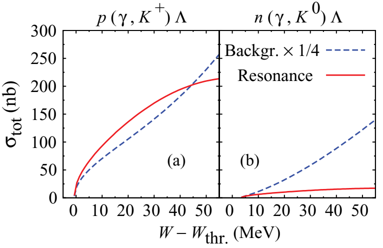


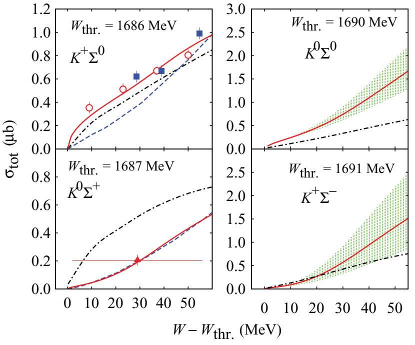
Issues and challenges:

- small cross sections ($\sigma_{tot} \sim$ few μb)
- weak decays of K/Y ⇒ smearing of CM angular resolution
- exclusive measurements required due to proton background
  - smaller detection efficiencies
  - further reduction of eff. when neutron in final state ($\epsilon_{\rm det} \sim 25\%$)
- Fermi motion
  ⇒ $W = (2E_\gamma m_n + m_n^2)^{1/2}$ from initial state smeared
  ⇒ reconstruct W from final state ⇒ worse resolution
- nuclear effects: FSI, coherent contributions
  ⇒ comparison of quasifree proton to free proton measurement

Elementary $\gamma N \to KY$ reactions

- theoretical description more straightforward at threshold
- no t-channel K^0 intermediate state for K^0 production
- resonance contributions might be small for $K^0\Lambda$
- more information about role of K_1 and K^* via $K^0\Lambda$ data
- some evidence for narrow state around 1650 MeV in $K\Lambda$ production off proton
- final-state interaction?

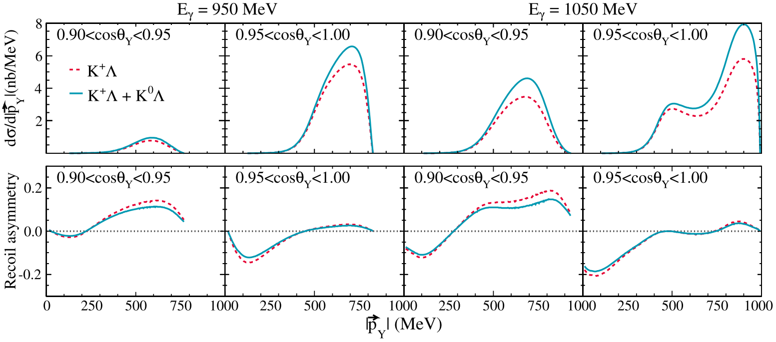




T. Mart, Phys. Rev. C 83 048203 (2011)
T. Mart, Phys. Rev. C 90 065202 (2014)

Study of *YN* and *KN* potentials

- FSI is the signal, not the background
- Ghent model: Regge-plus-resonance (RPR) and relativistic PWIA
- example: cross section and recoil asymmetry: $\gamma d \to \Lambda X$ (semi-inclusive)
- optimal phase-space regions to study the *YN* potential still to be found

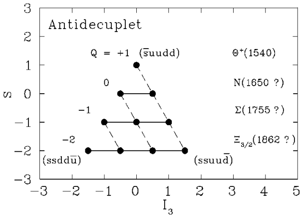


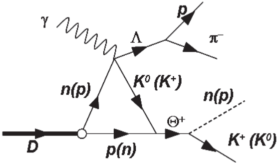
P. Vancraeyveld et al., Nucl. Phys. A 897 42 (2013)

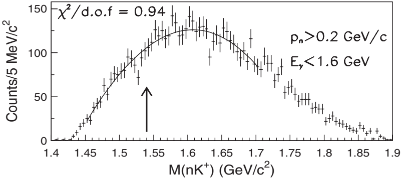
Exotic baryons?

Chiral quark soliton model
⇒ antidecuplet $\overline{\mathbf{10}}$ with $J^P = 1/2^+$

- nucleon-like $N(1680)$ in η production on neutron and Compton scattering?
- still positive results for $\Theta^+(1540)$:
  LEPS: $\gamma d \to K^+K^-pn$ (2009)
  CLAS split-off: $\gamma p \to pK_SK_L$ (2012)
  DIANA: K^+Xe $\to K^0p$Xe' (2014)
- $\gamma d \to \Lambda KN$ can be studied by A2
  - production via KN rescattering
  - strangeness tagging via Λ
  - less probability for artificial structures than KK channels
  - higher production rate for low E_γ
  - negative result from CLAS

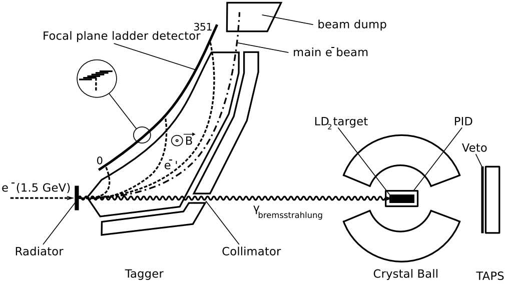


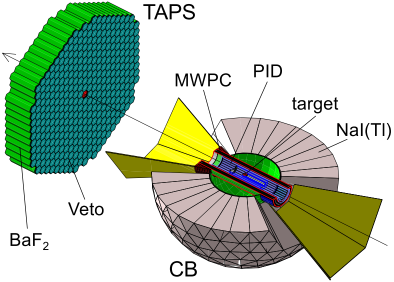




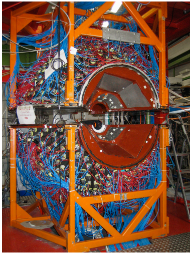
S. Niccolai et al., Phys. Rev. Lett. 97 032001 (2006)

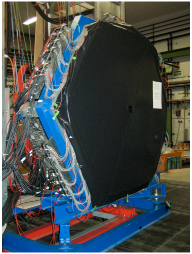
A2 setup in Mainz





- energy-tagged bremsstrahlung photons from 1.6 GeV MAMI electron beam
- $\sim 4\pi$ calorimeter system (CB + TAPS)
- charged particle vetos / basic tracking
- available neutron targets:
  - liquid deuterium (unpol.)
  - deuterated butanol (pol.)

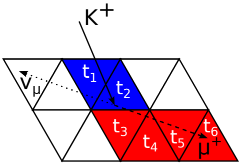




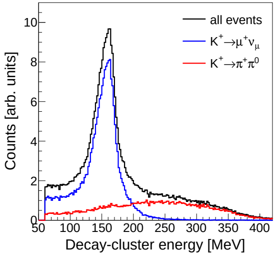
K^+ detection with the Crystal Ball

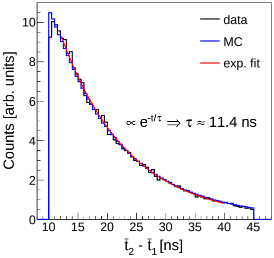
- detect K^+ decay inside NaI crystals
- separate impact and decay sub-clusters
- strong background removal through unique signature
- extract kinetic energy, decay energy and impact position
- good agreement with simulated distribution
- extracted K^+ lifetime close to $\tau_{K^+} \sim 12$ ns

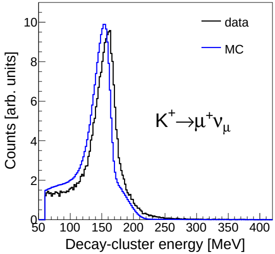
T.C. Jude et al., Phys. Lett. B 735 112 (2014)



$|t_2 - t_1| \leq 8$ ns
$|t_i - t_1| > 8$ ns; $3 \leq i \leq 6$







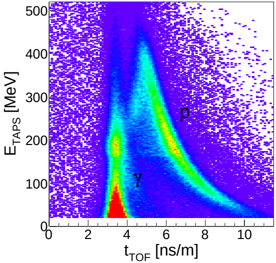
Reaction identification

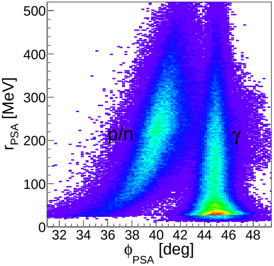
Reaction	Kaon decay	Hyperon decay	Detected
$\gamma n \rightarrow K^0\Lambda$	$K^0_S \rightarrow \pi^0\pi^0$	$\Lambda \rightarrow p\pi^-$	$4\gamma p\pi^-$
$\gamma n \rightarrow K^0\Sigma^0$	$K^0_S \rightarrow \pi^0\pi^0$	$\Sigma^0 \rightarrow \Lambda\gamma \rightarrow p\pi^-\gamma$	$5\gamma p\pi^-$
$\gamma n \rightarrow K^+\Sigma^-$	$K^+ \rightarrow \mu^+\nu_\mu$	$\Sigma^- \rightarrow n\pi^-$	$K^+n\pi^-$
$\gamma d \rightarrow \Lambda K^+ n$	$K^+ \rightarrow \mu^+\nu_\mu$	$\Lambda \rightarrow p\pi^-$	$K^+p\pi^-$
$\gamma d \rightarrow \Lambda K^0 p$	$K^0_S \rightarrow \pi^0\pi^0$	$\Lambda \rightarrow p\pi^-$	$4\gamma p\pi^-$

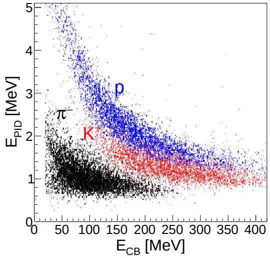
Decay	Γ_i/Γ
$K^0_S \rightarrow \pi^0\pi^0$	30.69%
$K^+ \rightarrow \mu^+\nu_\mu$	63.55%
$\Lambda \rightarrow p\pi^-$	63.9%
$\Sigma^0 \rightarrow \Lambda\gamma$	$\sim$100%
$\Sigma^- \rightarrow n\pi^-$	$\sim$100%

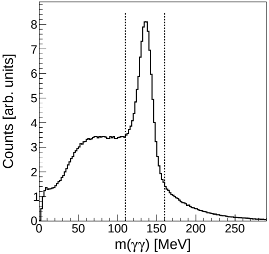
Particle identification

- neutral/charged discrimination using PID and Vetos
- TOF and PSA (BaF_2) in TAPS forward wall
- ΔE-E for CB (PID) and TAPS (veto) $\Rightarrow$ p and $\pi^{+/-}$ candidates
- K^+ via decay sub-cluster detection
- K^0 via best solution from kinematic fit of $K^0 \to \pi^0\pi^0 \to 4\gamma$ hypothesis









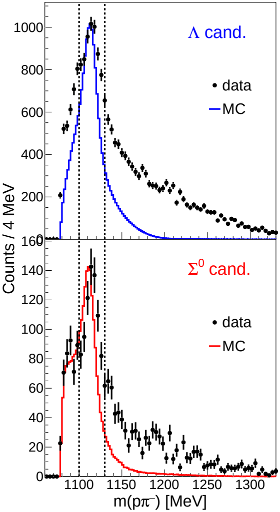
Analysis cuts and corrections

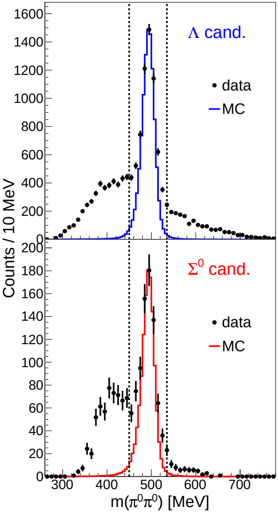
- π^- cluster size (energy resolution)
- TOF in TAPS (proton/neutron)
- $p\pi^-$ invariant mass (Λ)
- $\gamma\gamma$ invariant mass (π^0)
- $\pi^0\pi^0$ invariant mass (K^0)
- K-Y coplanarity
- $\gamma d \rightarrow KYX$ missing mass (proton)

Yet to be done:

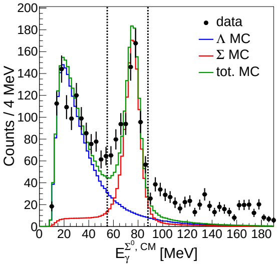
- energy corrections for K^+, π^-, p
- optimize efficiency of K^+ detection
- etc.

Very preliminary results for $\gamma n \to K^0 Y$

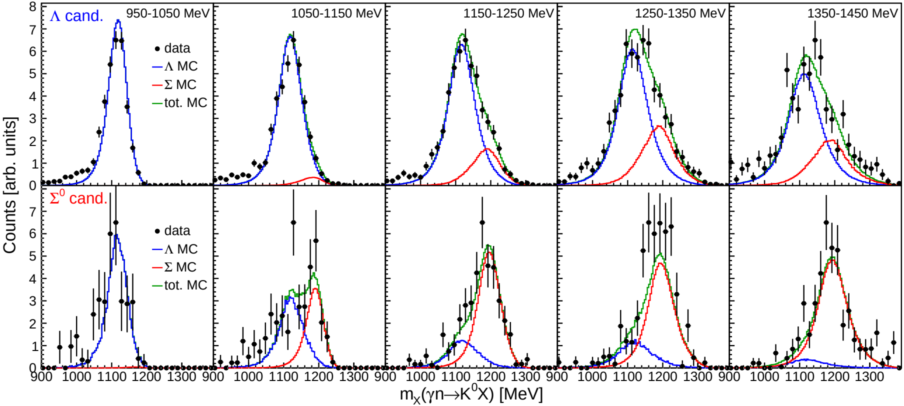




- clear Λ and K^0 signal
- clear Σ^0 signal via decay photon
- still some background to be reduced

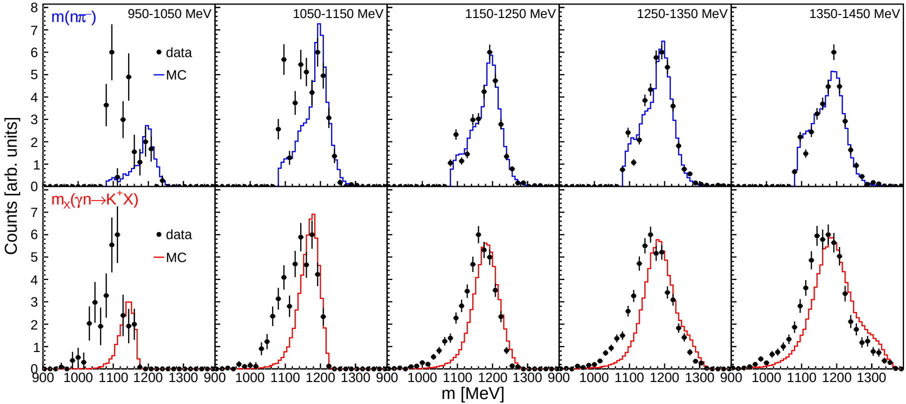


Very preliminary results for $\gamma n \to K^0 Y$



- Λ candidate: $4\gamma p\pi^-$ final state
- Σ^0 candidate: $5\gamma p\pi^-$ final state + cut on decay photon energy
- combined extraction of $\gamma n \to K^0\Lambda$ and $\gamma n \to K^0\Sigma^0$ signals

Very preliminary results for $\gamma n \to K^+\Sigma^-$



- reasonable agreement between data and MC
- more background studies needed

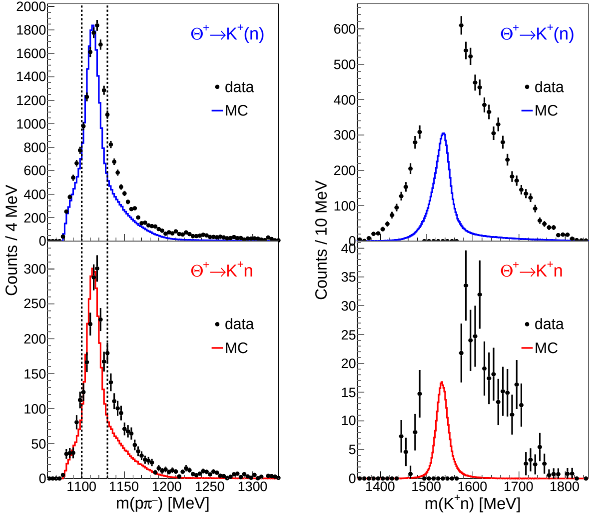
Pentaquark search in $\gamma d \rightarrow \Lambda K^+ n$

- analyze two potential $\Theta^+ \rightarrow KN$ decays:

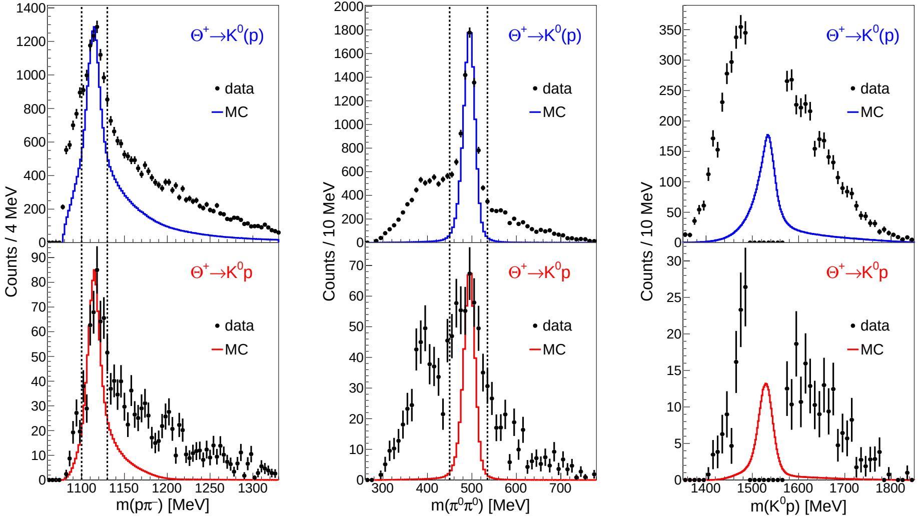
  $\gamma d \rightarrow \Lambda K^+ n$

  $\gamma d \rightarrow \Lambda K^0 p$

- use calculated or detected decay nucleon
- perform blind analysis $\Rightarrow$ $m(KN)$ masked from 1490 to 1570 MeV
- optimize cuts and corrections using visible region and other distributions
- unblind $m(KN)$ only in final analysis



Pentaquark search in $\gamma d \to \Lambda K^0 p$



Summary and outlook

Strangeness photoproduction using a deuteron target

- various physics motivations, especially at threshold
  - sparse experimental database for $\gamma n \to KY$ reactions
  - reduced complexity in theoretical description of elementary reactions
  - YN/KN potential studies through FSI
  - production of exotics via KN rescattering?
  - hypernuclear physics
- preliminary results of existing data look promising

Outlook:

- continue and finalize analysis of existing data: is there a peak?
- new high flux and high resolution photon tagger for A2
- optimize trigger for strangeness events
- new experiments?