Atomic cascade in kaonic hydrogen and deuterium

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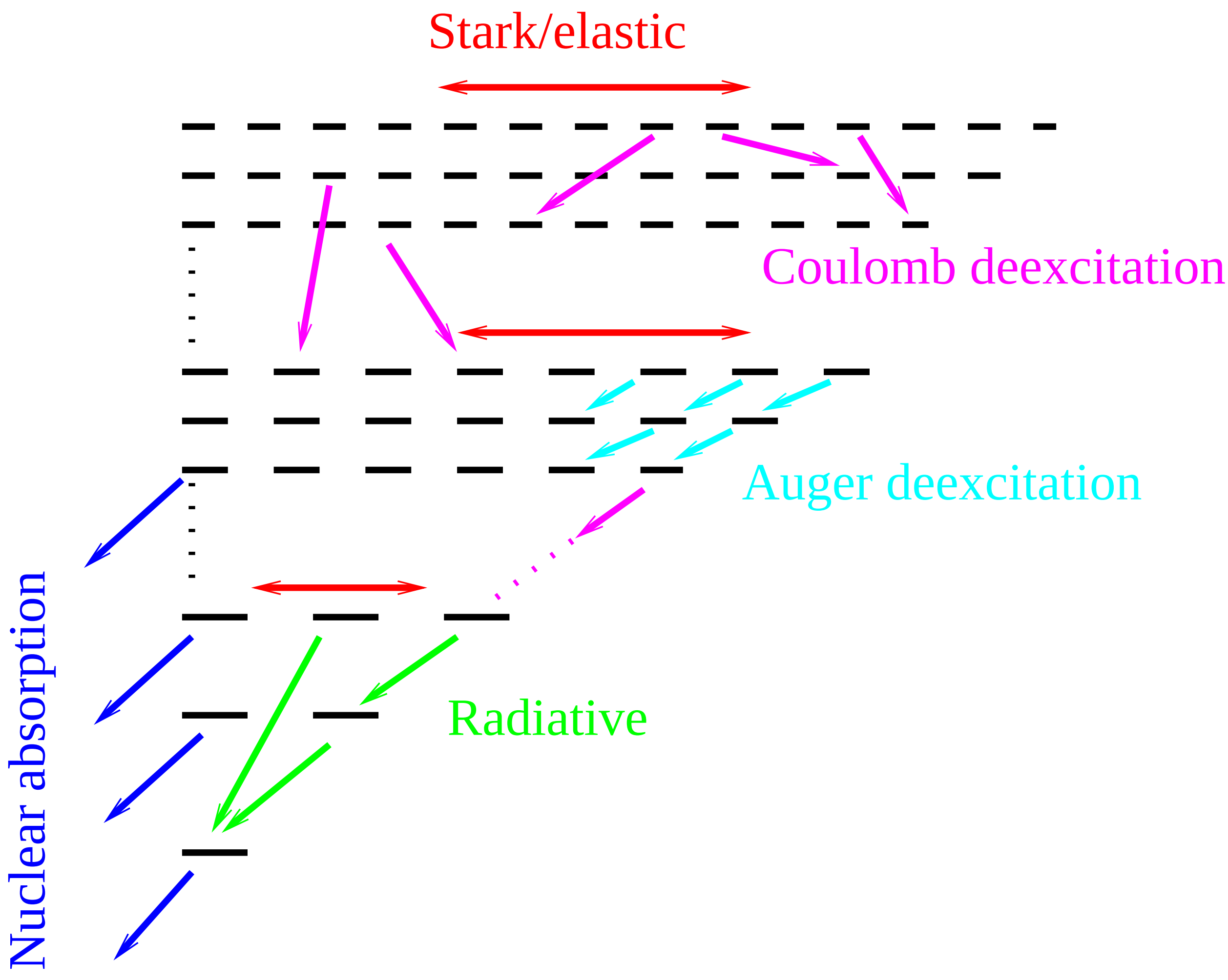
- Atomic cascade in exotic hydrogen
- Kaonic hydrogen
- Kaonic deuterium
- Summary

Cascade model



Coulomb deexcitation:

$$(K^-p)_{n_i} + \mathrm{H}_2 \to (K^-p)_{n_f}(E_1) + \mathrm{H}(E_2) + \mathrm{H}(E_3)$$

Auger deexcitation:

$$(K^-p)_{n_i} + \mathrm{H}_2 \to (K^-p)_{n_f} + \mathrm{H}_2^+ + e^-(E)$$

Cascade models

Standard cascade model: E_{kin} fixed through the cascade. (X-ray yields, cascade times)

Extended standard cascade model: Detailed kinetics calculations. (Doppler broadening corrections, $\mu p(2s)$ population, etc.)

Model	n	l	E_{kin}
Leon, Bethe (1962)	+	−	−
Borie, Leon (1980)	+	+	−
Reifenröther, Klempt (1989)	+	+	−
Markushin (1994)	+	+	+
Aschenauer, Markushin (1996)	+	+	+
Terada, Hayano (1997)	+	+	−
Faifman (2001)	+	+	+
Koike (2001)	+	+	+
T.J., Markushin (2002)	+	+	+

Experiments

- Kaonic hydrogen.
  X-ray yields. Theory ⇔ Experiment
  Determination of $\Gamma_{2p}^{\mathrm{had}}$.

- Kaonic deuterium.
  Yields high enough?
  Absolute X-ray yields.
  Structure of the K X-ray complex.

- Pionic hydrogen.

- Antiprotonic hydrogen.

- Muonic hydrogen.

Kaonic hydrogen X-ray yields

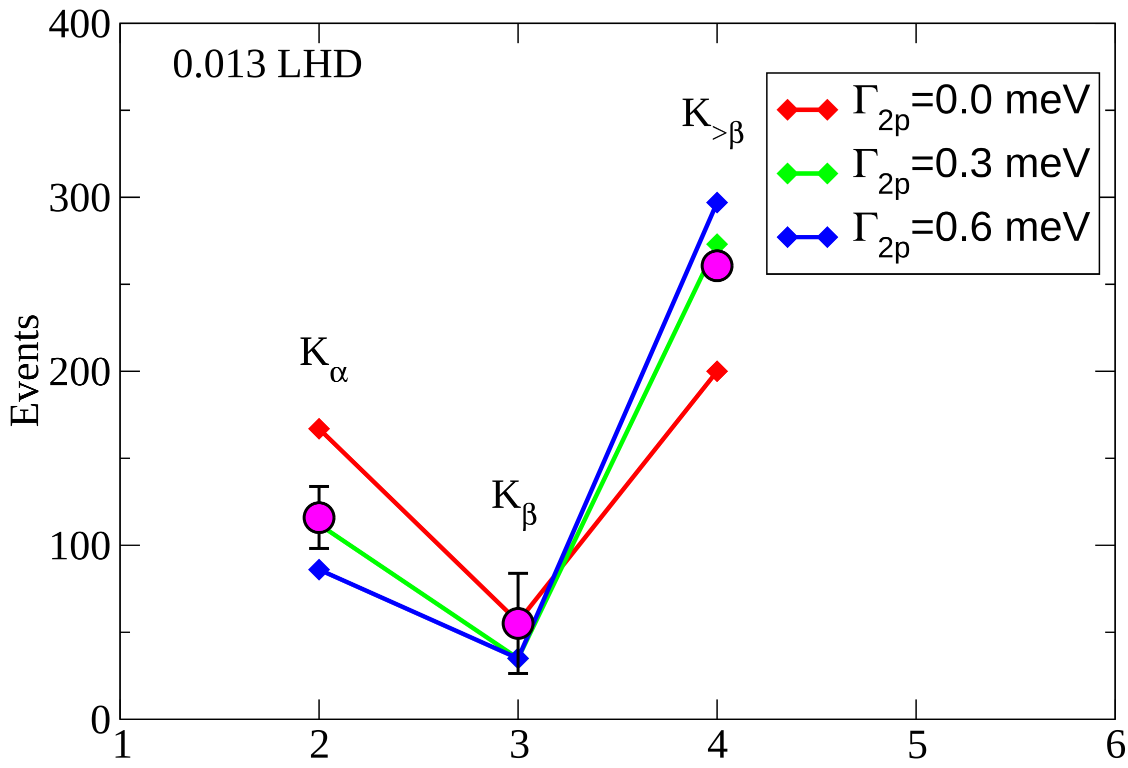
$\Delta E_{1s}^{\text{had}} = 323 \pm 63 \pm 11$ eV
$\Gamma_{1s}^{\text{had}} = 407 \pm 208 \pm 100$ eV
Iwasaki et al. 1997; Ito et al. 1998.

$\Delta E_{1s}^{\text{had}} = 193 \pm 37 \pm 6$ eV
$\Gamma_{1s}^{\text{had}} = 246 \pm 111 \pm 30$ eV
DEAR, 2004

Absolute K_α yields:
$1.5 \pm 0.5\%$ (KEK, 0.013 LHD) and
$1 - 3\%$ (DEAR, 0.031 LHD)
$\Rightarrow \Gamma_{2p}^{\text{had}} < 1$ meV

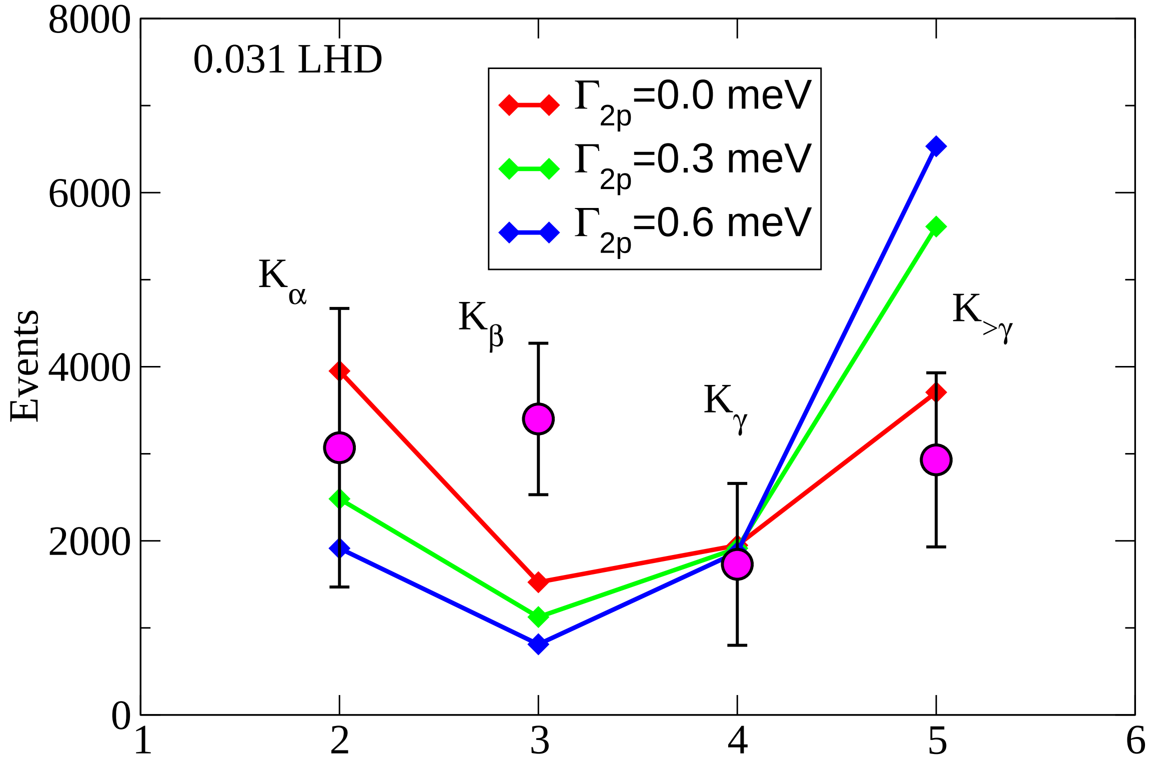
Relative X-ray yields are easier to measure and the cascade model predictions are more reliable.

Kaonic hydrogen X-ray yields



The relative X-ray yields in kaonic hydrogen at 0.013 LHD normalized to the experimental results of Ito et al. 1998.

Kaonic hydrogen X-ray yields



The relative X-ray yields in kaonic hydrogen at 0.031 LHD normalized to the preliminary results of the DEAR Collaboration. (Cargnelli, 2003)

High $K_\beta \Rightarrow$ Model needs improvement?

Kaonic deuterium X-ray yields

Feasibility: fx ~1% K_α at 20 bar

$\Delta E_{1s}^{\text{had}} \sim 500$ eV
$\Gamma_{1s}^{\text{had}} \sim 1000$ eV

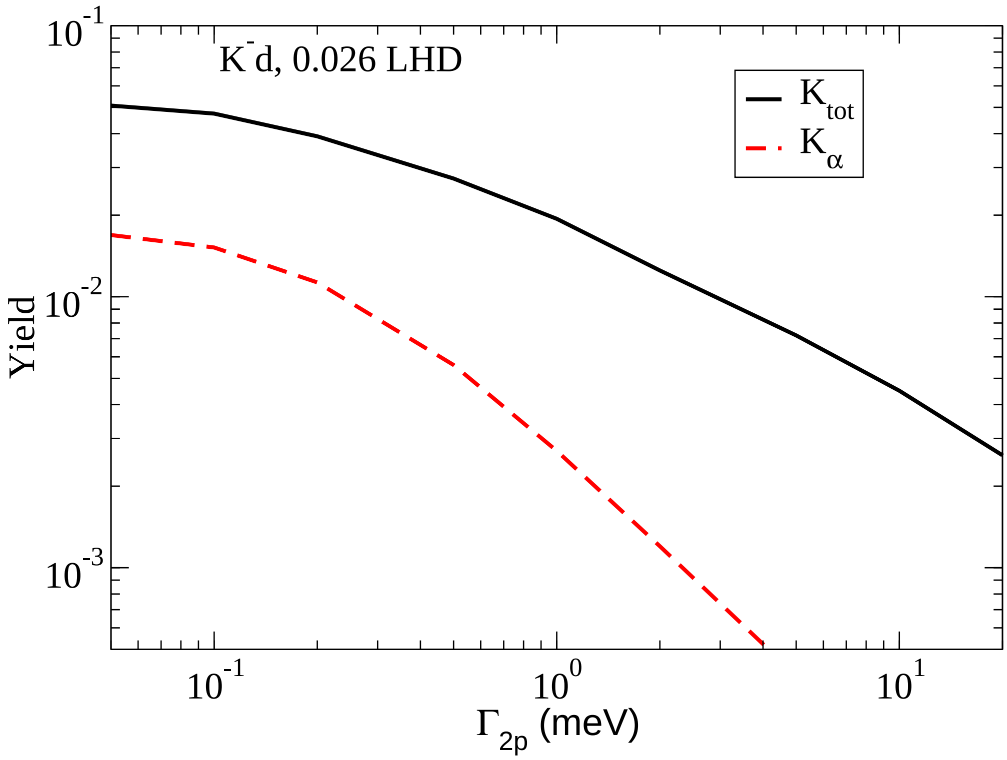
Predictions of the $2p$ width vary considerably:
$\Gamma_{2p}^{\text{had}} = 0.014$ meV Barrett, Deloff 1999
$\Gamma_{2p}^{\text{had}} = 4 \pm 2.3$ meV Faifman et al. 1999
$\Gamma_{2p}^{\text{had}} = 25$ meV Koike et al. 1996

The radiative width: $\Gamma_{2p}^{\text{rad}} = 0.3$ meV

p-state absorption can be a problem for future $K^- d$ X-ray experiments.

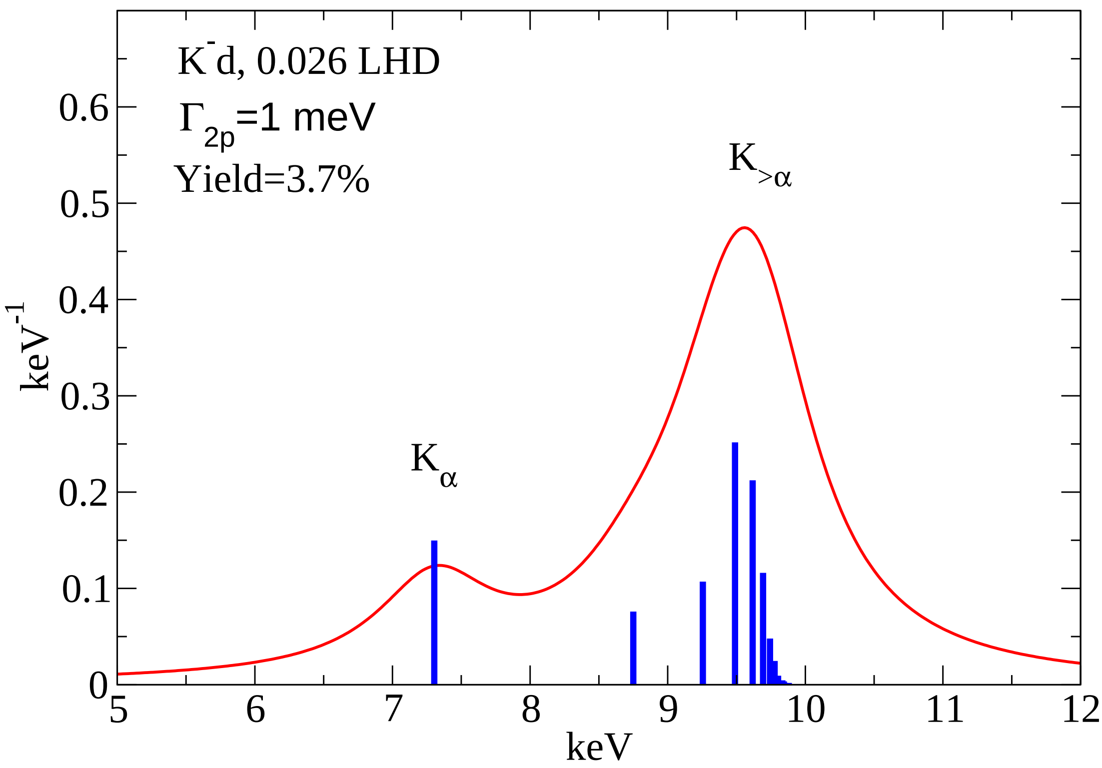
s-state absorption does not eliminate (nearly) all K X-rays in gas targets

Kaonic deuterium X-ray yields



The dependence of the X-ray yields in $K^{-}d$ on $\Gamma_{2p}^{\mathrm{had}}$.

Kaonic deuterium X-ray spectrum



Reliable predictions of relative X-ray yields
⇒ More accurate determination of Γ_{1s}^{had} and $\Delta E_{1s}^{\text{had}}$.

- Cascade model for exotic hydrogen atoms. Predictions available for μp, μd, $\pi^- p$, $K^- p$, $K^- d$, and $\bar{p}p$.

- Kaonic hydrogen. Cascade model predictions of relative X-ray yields have been compared to the experimental results.

- Kaonic deuterium. Feasibility of future experiments depends on Γ_{2p}^{had}. Reliable predictions of the K X-ray yields may be essential for a precise determination the $1s$ shift and width.