# Double-strangeness production by antiprotons

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New Opportunities in the Physics Landscape of CERN
CERN, May 12, 2009

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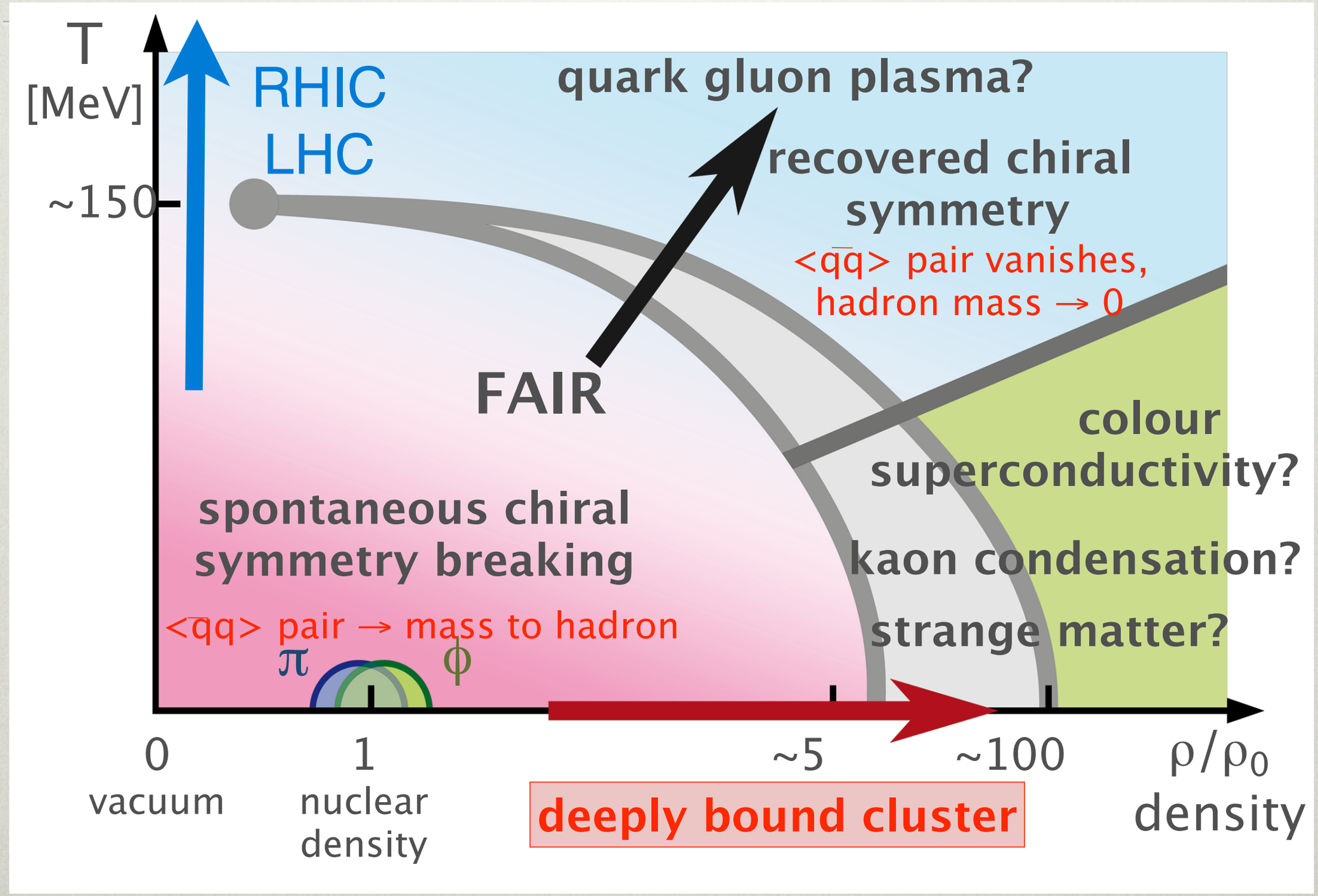
# Antikaon-Nucleon Interaction

- Hot topics in low-energy QCD
  - strongly attractive in isospin 0 channel
  - details under debate, problems between scattering data and exotic atom data (KpX, DEAR)
  - different theoretical descriptions
- Akaishi & Yamazaki 2002:
  - strong attraction leads to deeply bound nuclear states $K^-pp$, $K^-ppn$, **$K^-K^-pp$**, etc.: KNC
  - Binding energies 100 MeV and more, high density
  - *highly debated* among theoretical community

# Motivation


T
[MeV]
~150
RHIC
LHC
FAIR
quark gluon plasma?
recovered chiral
symmetry
<q̄q> pair vanishes,
hadron mass → 0
colour
superconductivity?
kaon condensation?
strange matter?
spontaneous chiral
symmetry breaking
<qq> pair → mass to hadron
π
ϕ
0
vacuum
1
nuclear
density
~5
~100
ρ/ρ0
density
deeply bound cluster

# Experimental Search for Single-K Cluster

- Phase I experiments finished (single-K)
  - KEK E471/E549, Finuda@DAΦNE
- Analysis of old experiment data
  - OBELIX@LEAR, DISTO@SATURNE
- 2nd generation experiments under way
  - E15@J-PARC, FOPI@GSI, AMADEUS@ DAΦNE2
  - missing mass & invariant mass spectroscopy
  - detection of all secondary decay products

# Search for double-bound KNC using antiproton annihilation at rest

- Creation of kaons in high density nuclear matter: antiproton annihilation
- Basic reaction (endothermic by 98 MeV)

$$\overline{p} + p \rightarrow K^+ + K^+ + K^- + K^-$$

**Idea:** P.Kienle [(1)], T.Yamazaki and W.Weise [(2)]

(1) Int. Jour. Mod. Phys. A 22 (2007)365

(2) arXiv:nucl-th/0507058 v1 (2005)

# First experimental hints

- OBELIX data:
  - Yields for strangeness production S=-2

$$K^+ + K^+ + p + \Sigma^- + \Sigma^- \quad : \quad (0.17 \pm 0.04) \times 10^{-4}$$
$$K^+ + K^+ + n + \pi^- + \Sigma^- + \Sigma^- \quad : \quad (2.71 \pm 0.47) \times 10^{-4}$$
$$K^+ + K^+ + n + \Lambda^0 + \Sigma^- \quad : \quad (1.21 \pm 0.29) \times 10^{-4}$$
$$K^+ + K^+ + n + n + K^- + \Lambda^0 \quad : \quad (1.21 \pm 0.29) \times 10^{-4}$$

$S = -2$ strangeness production in $\bar{p}^4$He annihilations at rest

G. Bendiscioli [a], T. Bressani [b], L. Lavezzi [a,*], A. Panzarasa [a], P. Salvini [a]

Nuclear Physics A 797 (2007) 109–130

# Exclusive Measurement

- Formation process (if binding energy []>100 MeV)

$$\overline{p} + {}^4He \rightarrow \boxed{K^+ + K^+} + [pnnK^-K^-]$$

- Decay processes

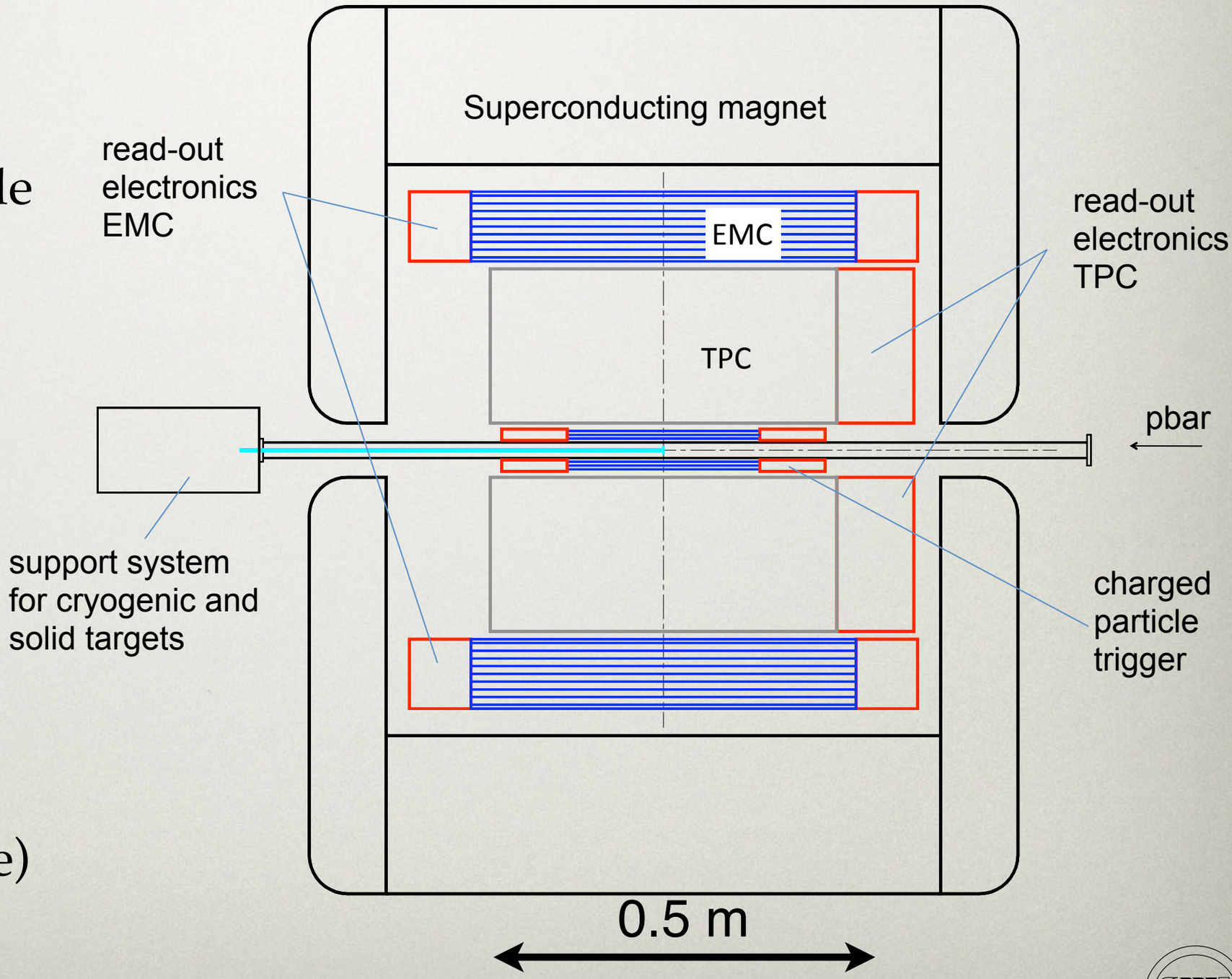
$$\begin{aligned} [pnnK^-K^-] \quad &\rightarrow \quad p + \Sigma^- + \Sigma^- \\ &\qquad\quad p + (n + \pi^-) + (n + \pi^-) \end{aligned}$$

$$\begin{aligned} [pnnK^-K^-] \quad &\rightarrow \quad n + \Lambda^0 + \Sigma^- \\ &\qquad\quad p + (p + \pi^-) + (n + \pi^-) \end{aligned}$$

$$\rightarrow \boxed{p + 2\pi^- + 2n}$$

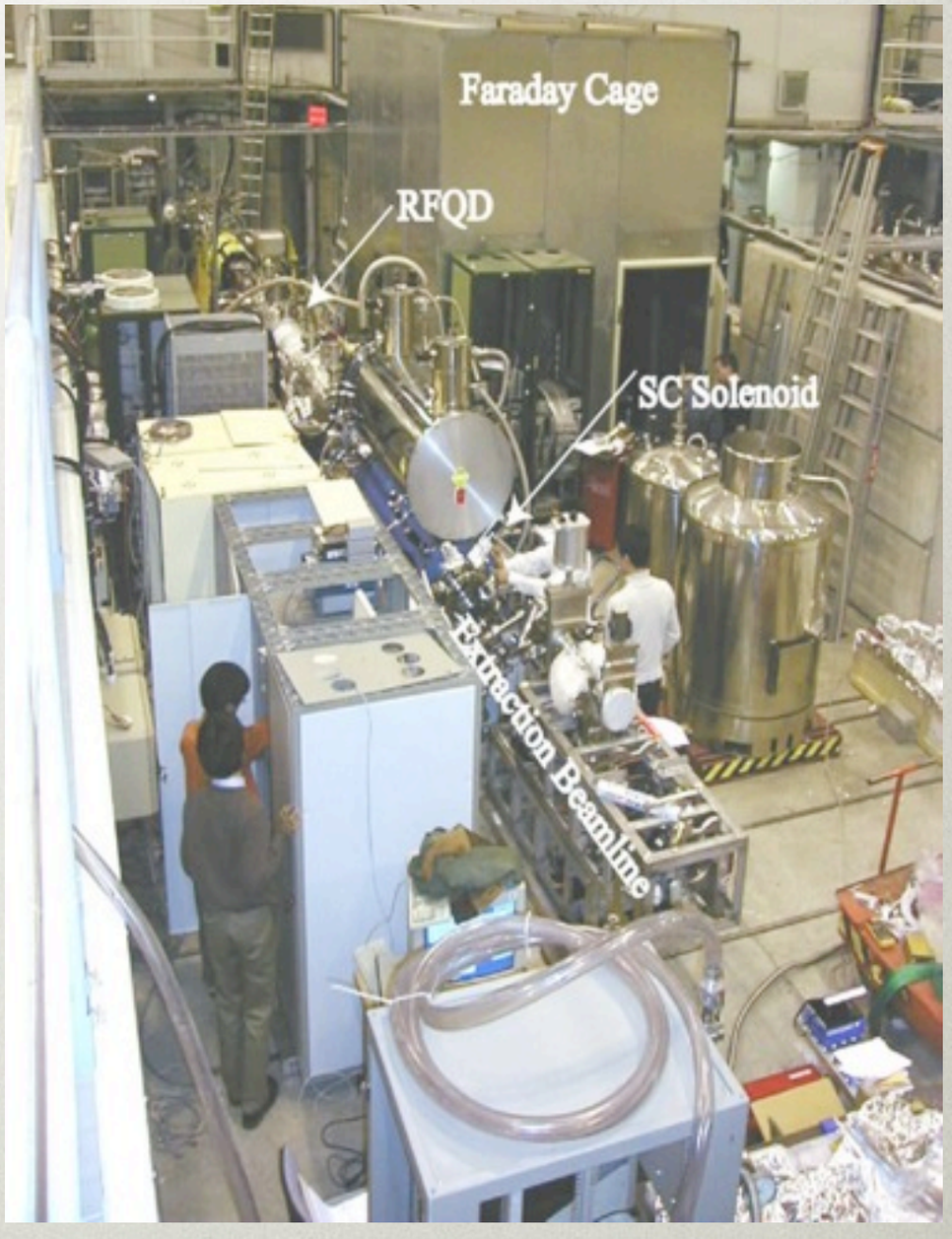
# Detector

- Start counter – scintillating fibres with Geiger Mode APD readout
- PID – with a TPC - GEM (FP7 Hadron Physics 2)
- For neutral particle detection - a Calorimeter with alternating scintillating fibers - lead layers (KLOE-type)



# Beam

- Continuously extracted beam of low-energy antiprotons needed
- MUSASHI@AD
  - rate few $10^3$/s
  - energy few keV
  - targets: frozen $D_2$, solid Be, Li



# Crude Rate Estimate

- Using Obelix results for

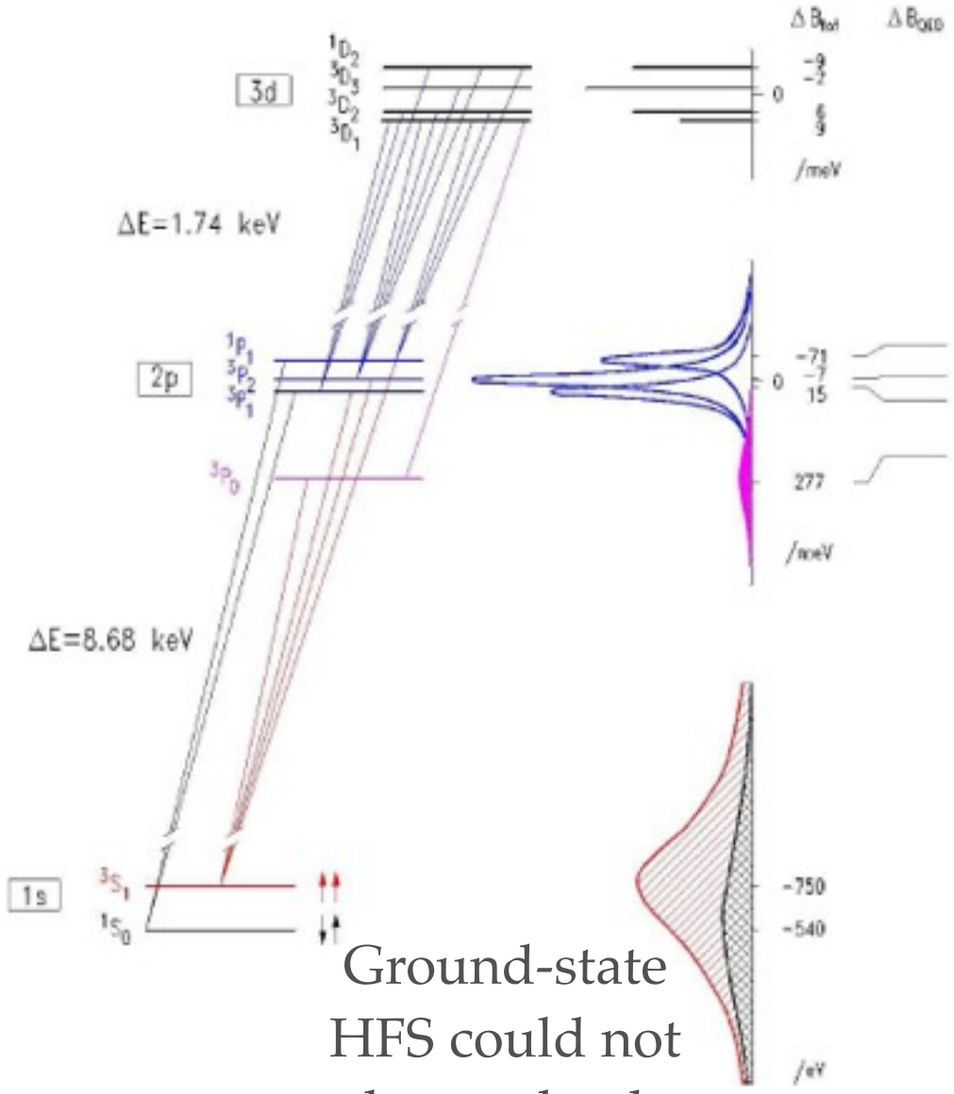
$$K^+ + K^+ + p + \Sigma^- + \Sigma^- \quad \Rightarrow \quad (0.17 \pm 0.04) \times 10^{-4}$$

$$K^+ + K^+ + n + \Lambda^0 + \Sigma^- \quad \Rightarrow \quad (1.21 \pm 0.29) \times 10^{-4}$$

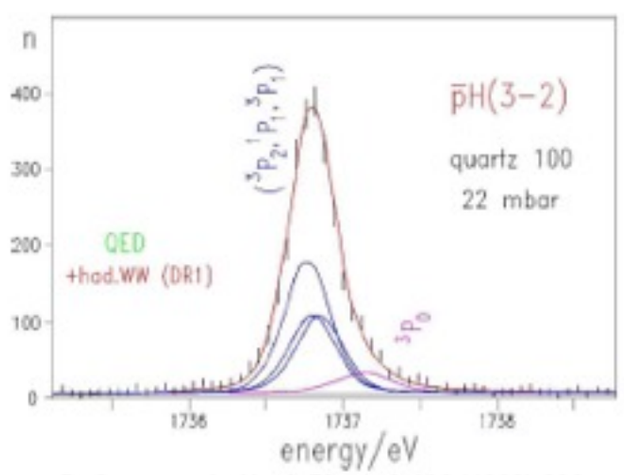
  - pbar rate ~ $10^3$ $s^{-1}$
  - stopped pbars ~ 50%
  - overall detector efficiency ~10%
- ~ 75 $K^+K^+$-pairs produced per day!
- ~ 500 $K^+K^+$-pairs produced per day!

# X-rays of light pbar atoms

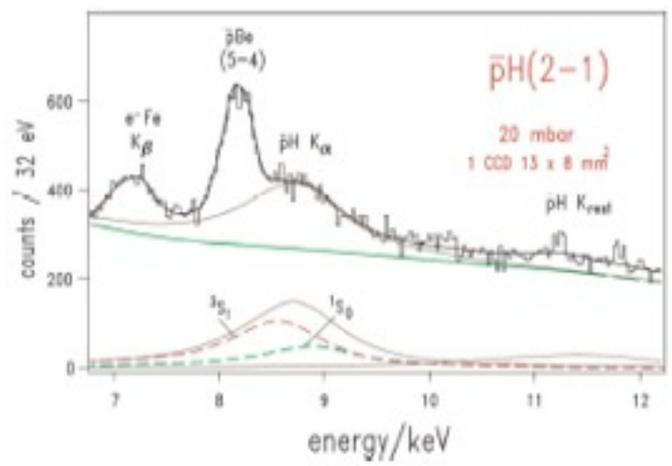
## D. Gotta Abstract #50




Ground-state HFS could not be resolved




D. Gotta et al., Nucl. Phys. A 660 (1999) 283




M. Augsburger et al., Nucl. Phys. A 658 (1999) 149

- Continuous pbar beam needed: MUSASHI
- Low-energy nucleon-antinucleon interaction
- Isotope effects: relative strength of annihilation p,n: halo effects

High resolution crystal spectrometer: FLAIR

# Conclusions

- Continuous MUSASHI beam enables first studies for nuclear/particle physics experiments
  - double strangeness production, pbar X-rays
- DSP looks promising based on Obelix data
- Early stage idea, more thoughts/collaborators needed
- R&D started on GEM-TPC (JRA in HadronPhysics2)
- MUSASHI: frozen $D_2$ or solid targets
- more detailed studies with variety of gases
  - high-intensity higher energy continuous beam
  - FLAIR