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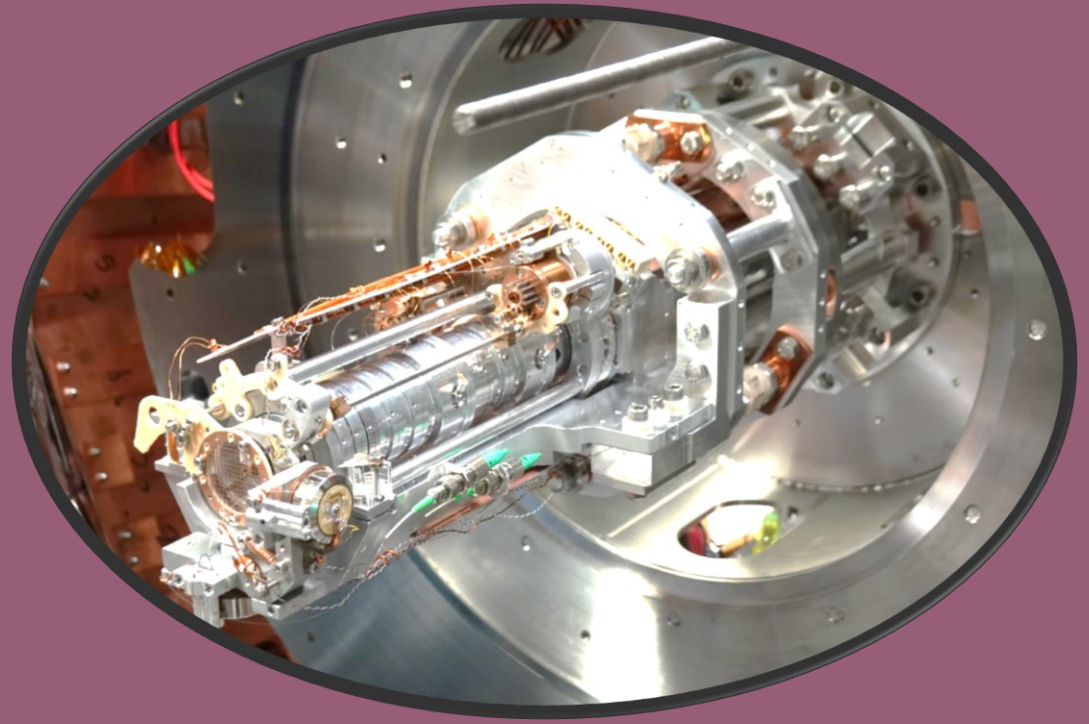

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no. 2022/46/E/ST2/00255

Antiprotonic atoms as gateways for dark matter

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Ministerstwo Edukacji i Nauki

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The sexaquark S

is a hypothesized deeply bound, long-lived or stable 0+ state of *uuddss* quarks with **B=+2, S=–2 and Q=0.**

- If $m_S < m_\Lambda + m_p + m_e = 2.054$ GeV → decay must be **doubly-weak and its lifetime would be greater than the age of the Universe**.
- Direct detection experiments have not yet probed the relevant mass.
- The stability of neutron stars is not affected by the sexaquarks, due to deconfinement.

M. Doser, G. Farrar, GK, arXiv:2302.00759 [hep-ph]

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Three attributes of a stable S make it very difficult to detect

- The S is **neutral** and a **flavor singlet**, so it does **not couple to photons**, **pions** and most other mesons, nor does it leave a track in a detector.
- The S has **no pion cloud** and is expected to be **more compact than ordinary baryons**. This means the amplitude for interconversion between S and baryons is small.
- The mass of the S makes it **difficult to distinguish from** the much more copious **neutron**.

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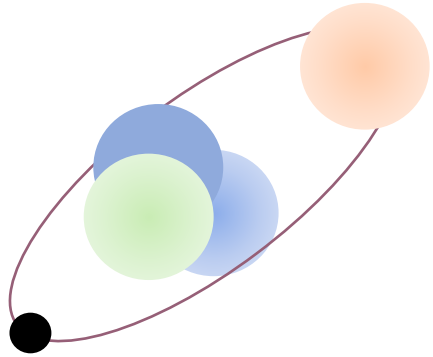
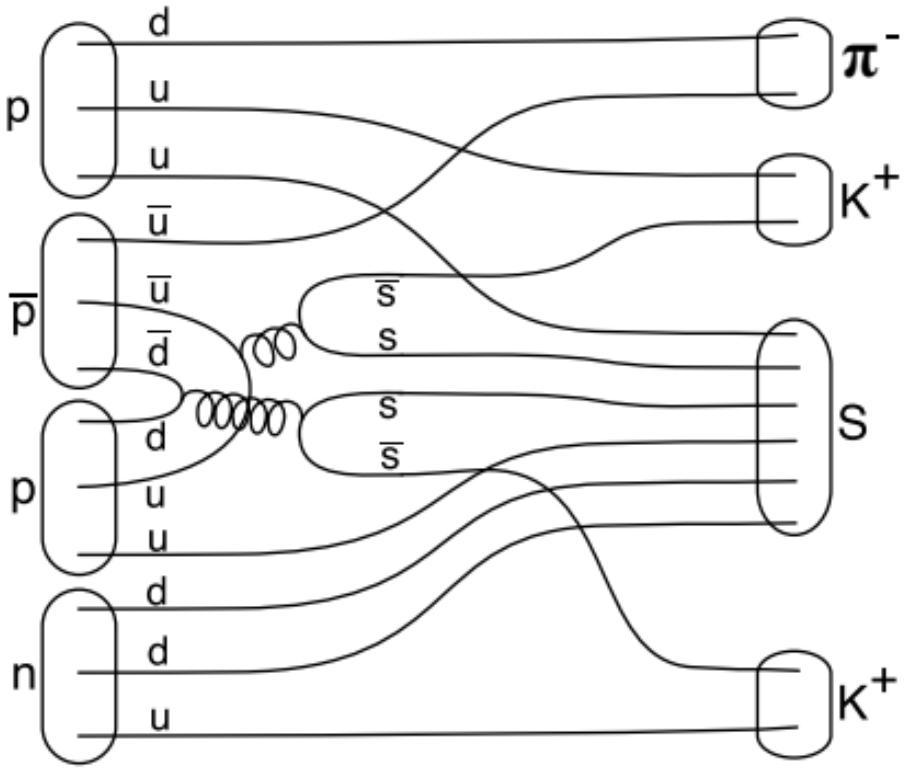
Anti-protonic 3He as gateway of S

M. Doser, G. Farrar, GK,
arXiv:2302.00759 [hep-ph]





$m_{\bar{p}} + m_p + m_p + m_n \sim 3750$ MeV

Formation mechanism for antiprotonic atoms can be used to test the existence of the S sexaquark (uuddss)

Expected rate ~10^{-9}

$$(uuddss) + \pi^- + K^+ + K^+ \text{ (in } 2/3 \times 1/3 \text{ of the cases)}$$
$$(uuddss) + \pi^+ + K^0 + K^0 \text{ (in } 1/3 \times 1/3 \text{ of the cases)}$$
$$(uuddss) + \pi^0 + K^0 + K^+ \text{ (in } 2/3 \times 2/3 \text{ of the cases)}$$
$$(uuddss) + \pi^0 + K^0 + K^+ \text{ (in } 1/3 \times 2/3 \text{ of the cases)}$$

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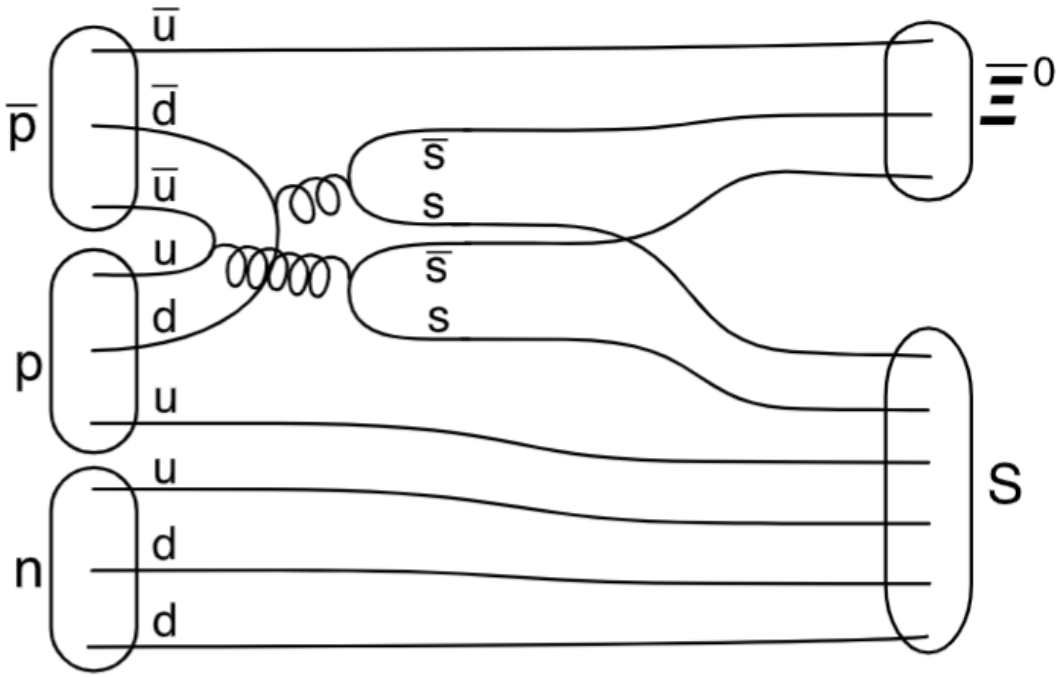
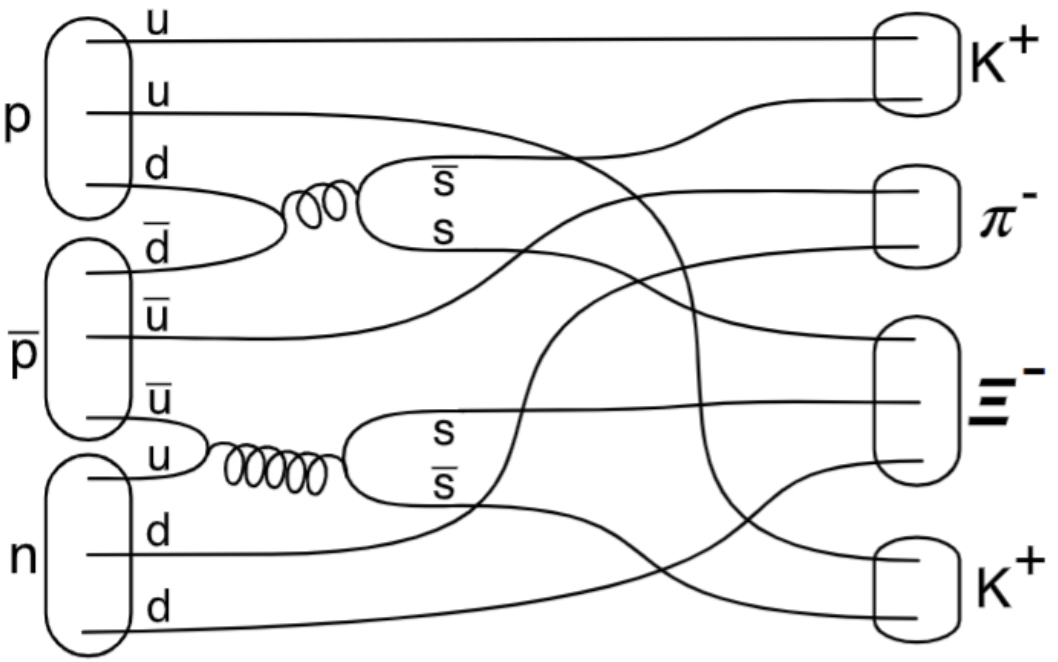
Other possible channels and background

M. Doser, G. Farrar, GK,
arXiv:2302.00759 [hep-ph]





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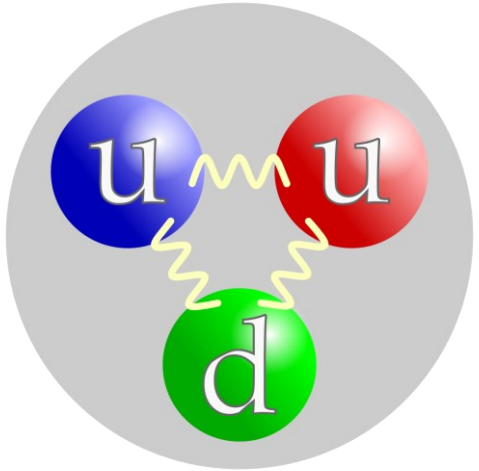
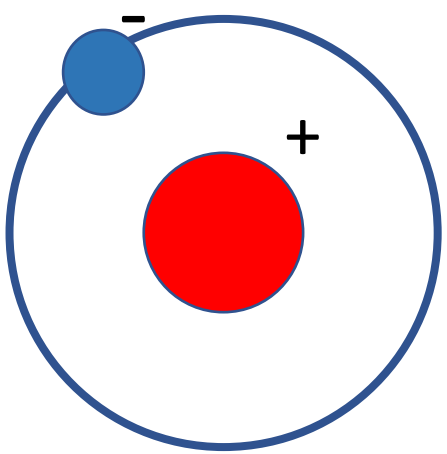
The antinucleons, antihydrogen and other exotic atoms

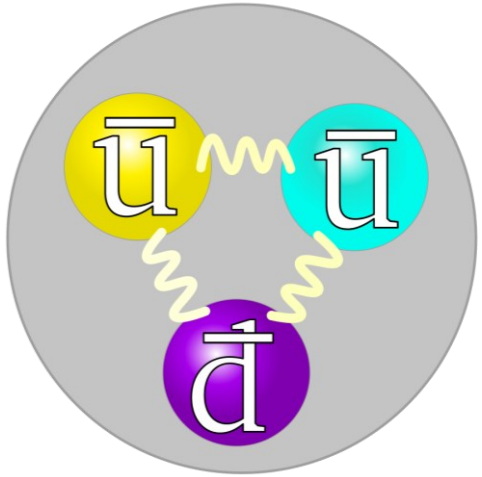
proton



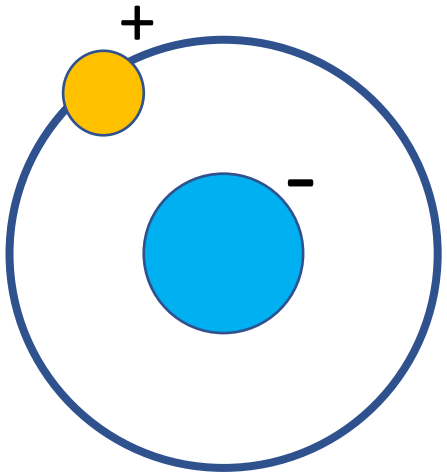
hydrogen



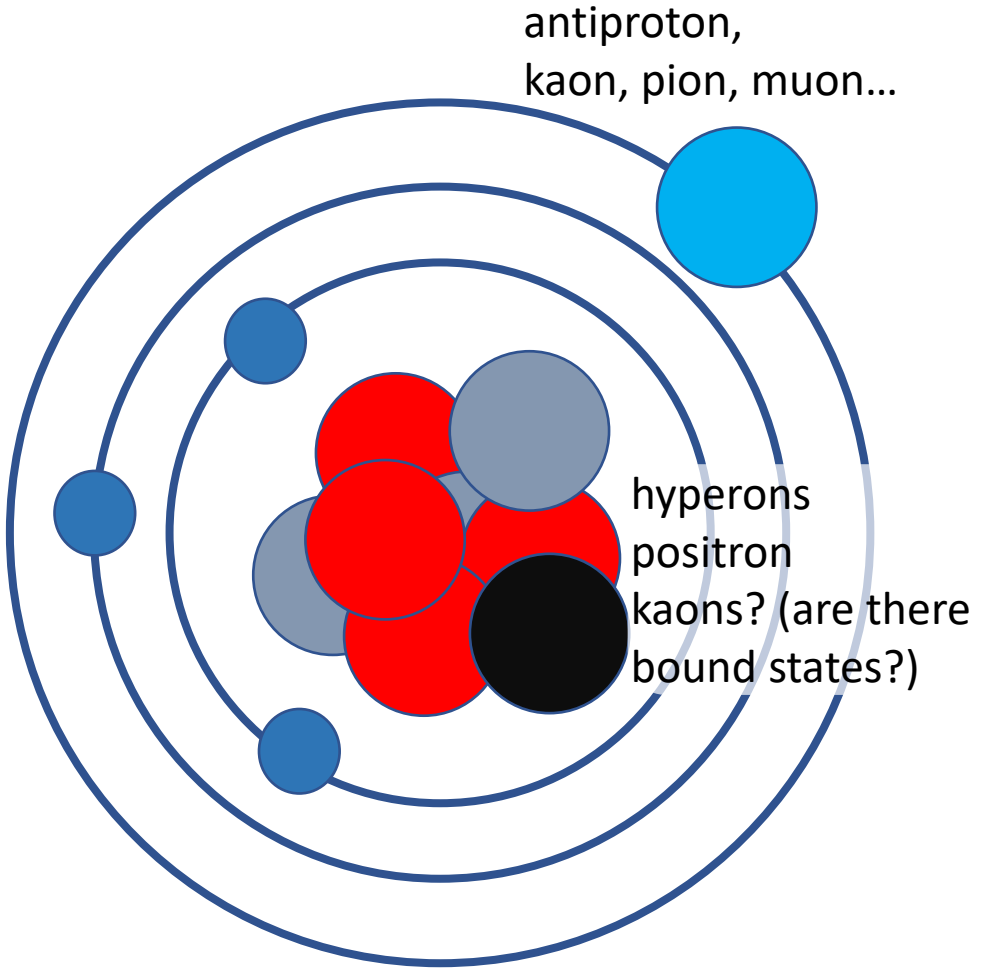
antiproton



antihydrogen



Exotic atoms



Positronium, protonium, pionic, kaonic, muonic, antiprotonic…

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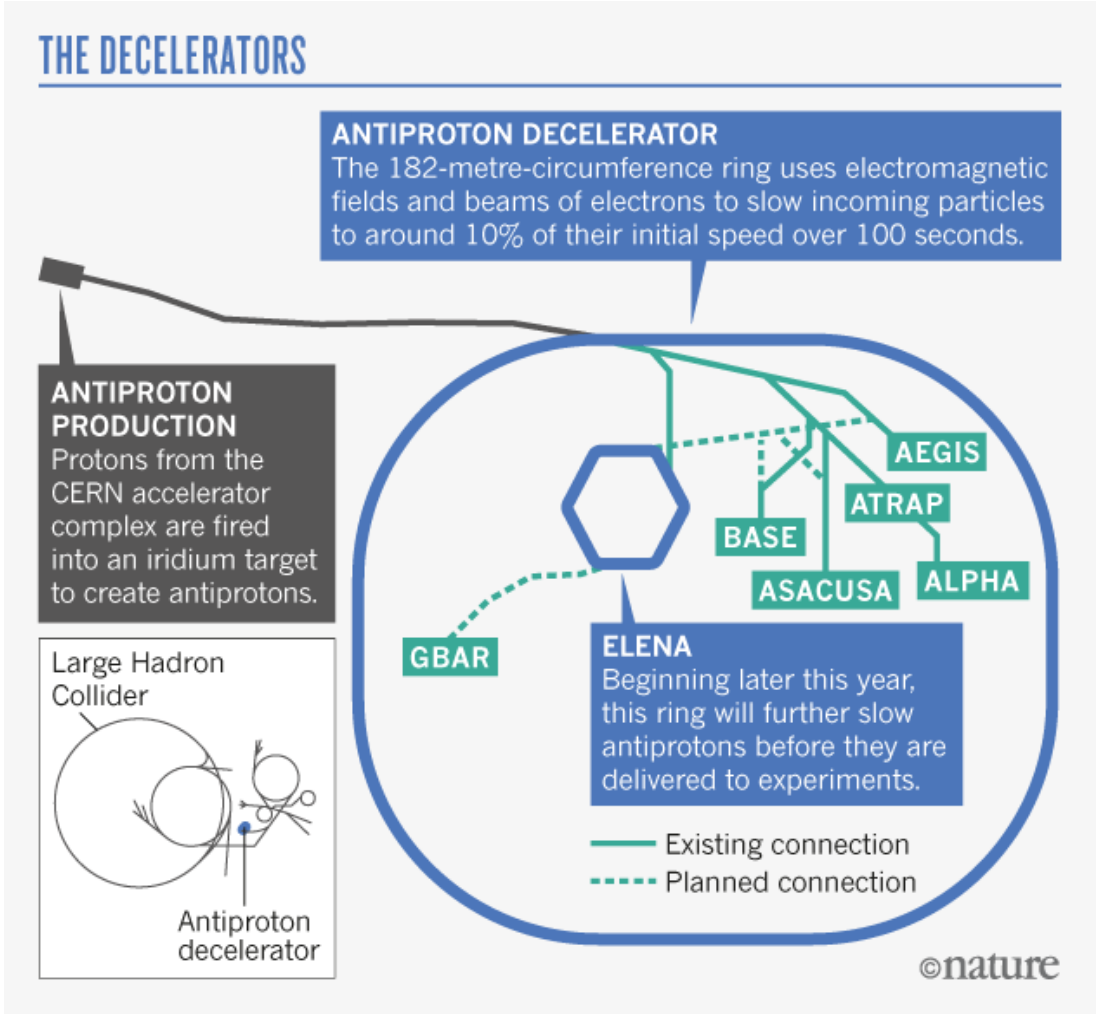
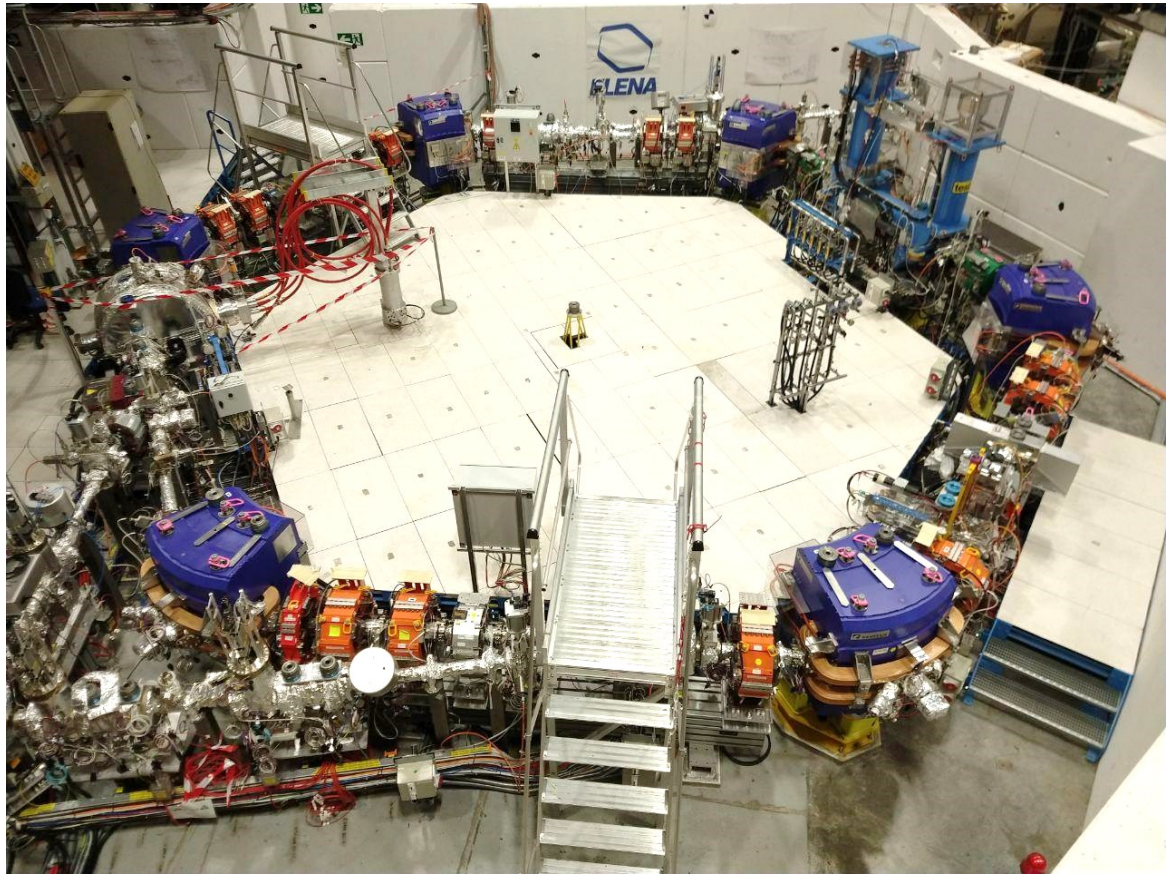
Antiproton Decelerator and ELENA: 100 keV antiprotons





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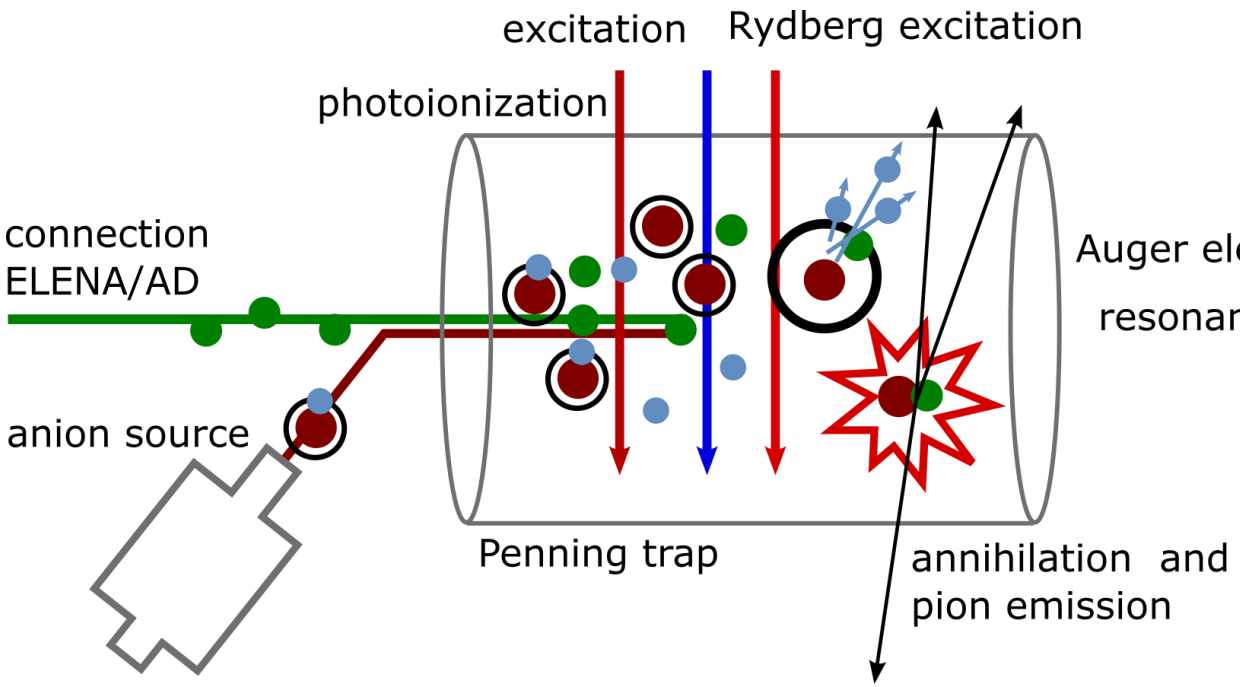
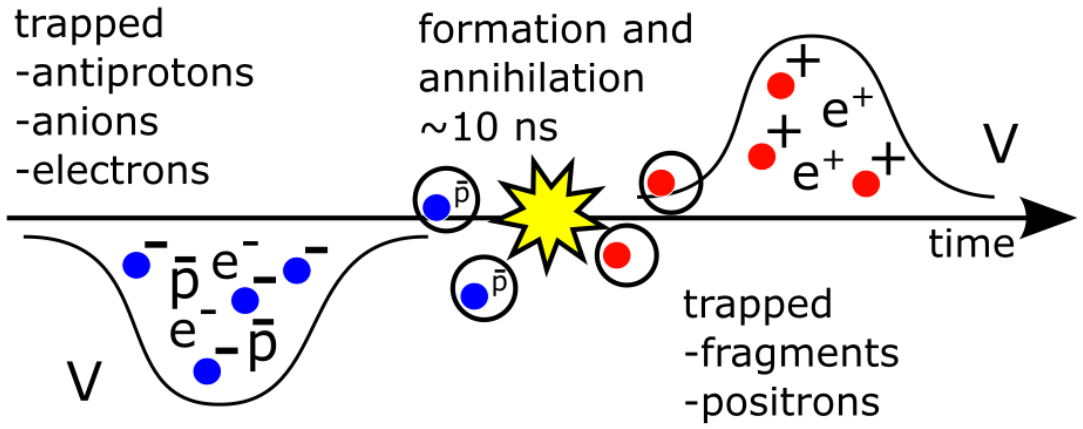
Scheme of production of pulsed and cold antiprotonic atoms



"Synthesis of cold and trappable fully stripped HCl's via antiproton-induced nuclear fragmentation in traps"
G. Kornakov et al., PRC **107**, 034314 (2023)

1st step: resonant formation of antiprotonic atoms

S. Gerber et al., Pulsed production of cold protonium in Penning traps, Phys. Rev. A 100, 063418 (2019)



2nd step: trapping of highly-charged fragments;

- **Nested Penning trap**

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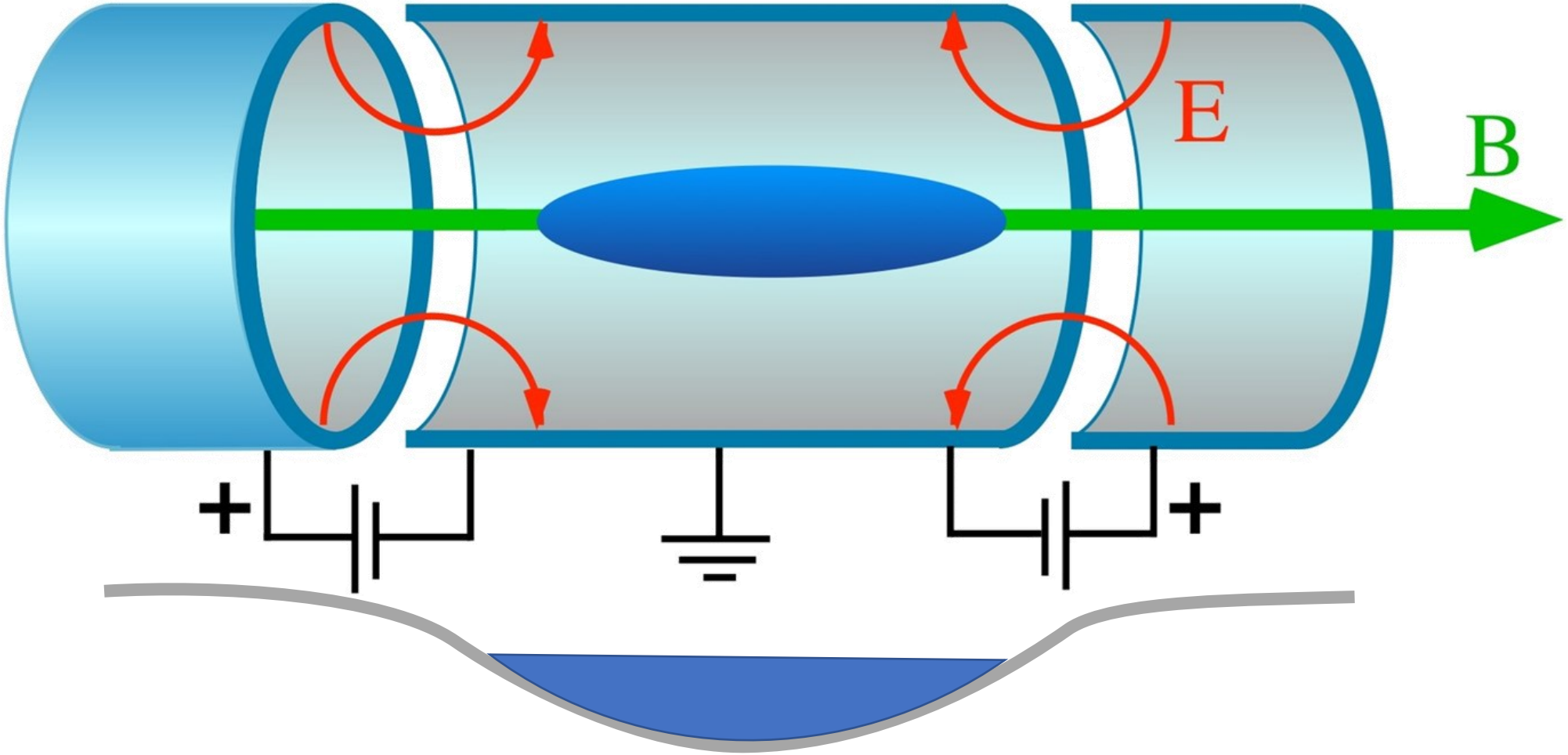
Malmberg-Penning trap

Cylindrically symmetric traps with a uniform axial magnetic field for radial confinement and potentials on electrodes provide axial confinement.



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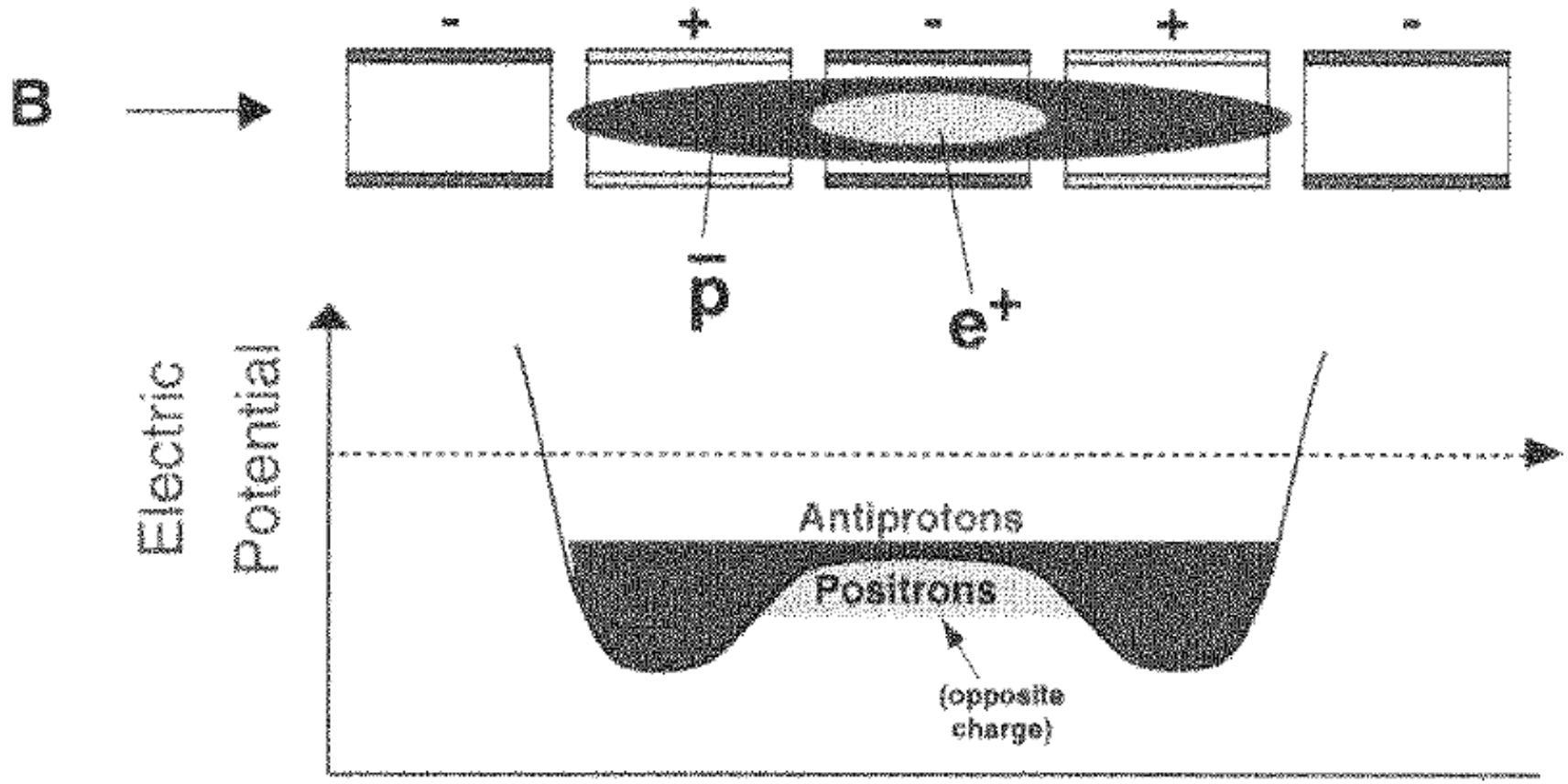
Nested Malmberg-Penning traps

Helium-3 ions can be mixed with antiprotons !



M H Holzscheiter and M Charlton 1999 *Rep. Prog. Phys.* **62** 1

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Simulated signal and background

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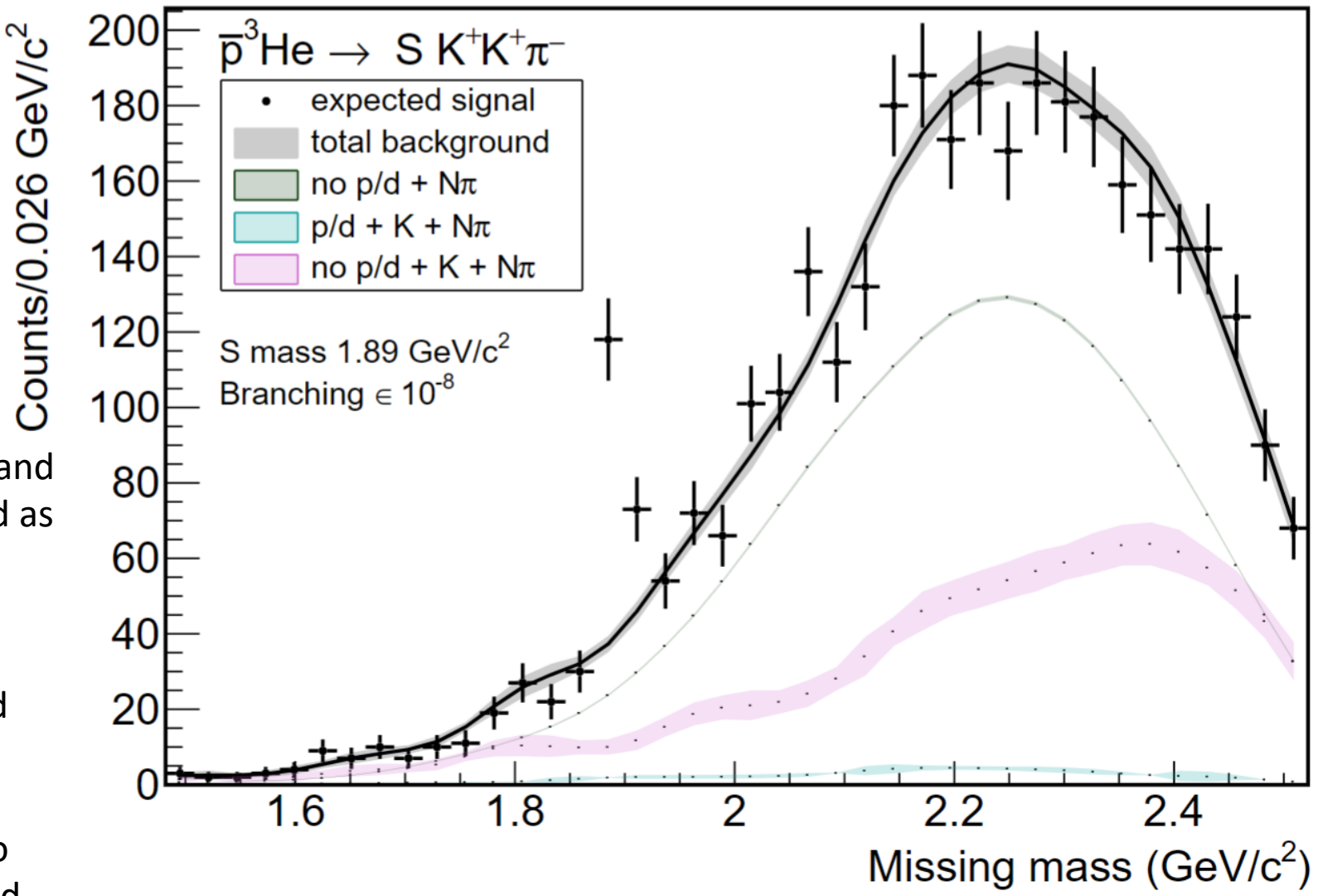
- All known processes
- Detector inefficiency
- Missidentification

most of the background events are:
1. lost low energy deuteron or proton with one negative pion and two positive pions misidentified as kaons
2. lost low energy proton or deuteron, kaon and two pions, one misidentified as the second kaon
3. inefficient reconstruction of proton/deuteron, kaon and two pions, one of them misidentified.



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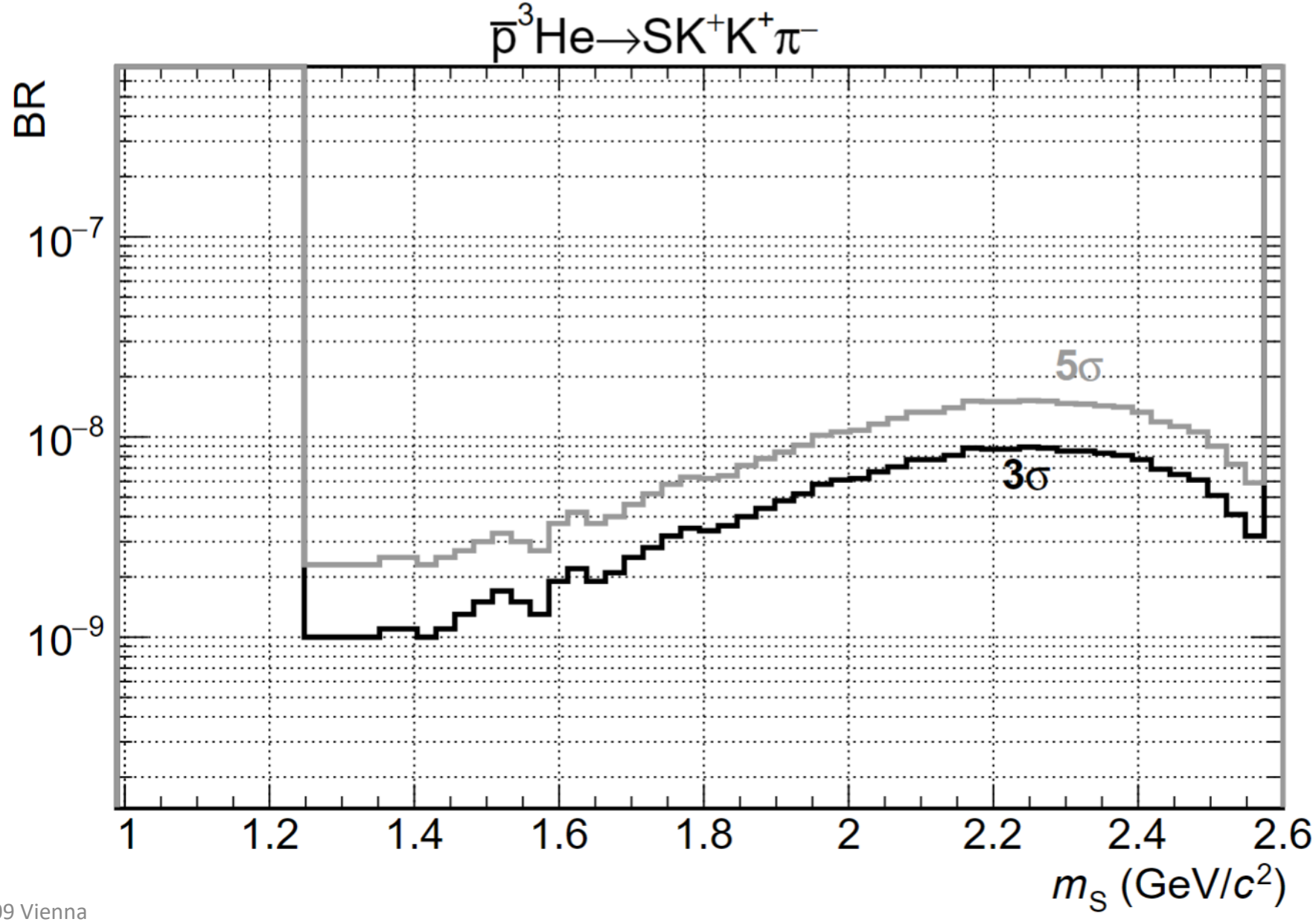
Sensitivity to different BR



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Summary and conclusions

- The S sexaquark can be a good candidate for DM
- Its properties: neutral, compact, no pion cloud makes it very difficult to detect.
- A dedicated experiment based on formation of antiprotonic helium-3 in traps can produce clean signals.
- 1-year of data can be sufficient to reach sensitivities to BR of 10^{-9}

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Thank you for your attention!

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