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The PUMA Experiment: Antiprotons En Route to ISOLDE

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Number of participants: 27 persons in 30/7-018 - Kjell Johnsen Auditorium (CERN) + 31 people connected through Zoom (= 34 - room - Elias - Thierry)

- The presentation from Lukas was divided into 3 parts
  - Motivation (nuclear structure of exotic nuclei)
  - PUMA at AD (antimatter at AD, particle traps, and detectors)
  - PUMA at ISOLDE (radioactive ions at ISOLDE, new RC6 beamline)
- **Motivation**
  - The general nuclear landscape (with its number of neutrons on the horizontal axis and its number of protons on the vertical axis) was first reviewed
  - Several nuclear structure experiments can be performed depending on the energy (mass spectroscopy, laser spectroscopy, gamma spectroscopy, etc.)
  - Exotic nuclei can exhibit halo structure and neutron skins, which reflect in neutron and proton densities => It has so far only been probed at high energies or large distances (it requires techniques that: probes tail of matter distribution; probes neutron fraction; is applicable to unstable nuclei)
  - PUMA = antiProton Unstable Matter Annihilation => Technique = low-energy antiprotons as a probe
    - Capture in excited antiproton orbital
    - Cascade: Auger transitions
    - Cascade: radiative transitions
    - Annihilation with surface nucleon
    - Final-state interactions of emitted mesons
  - It is not a new idea, the first application was done at BNL in 1973 by Bugg et al.
  - PUMA aims to
    - Provide new nuclear observable R (proton-to-neutron annihilation ratio, related to Halo factor)
    - Characterize nuclear density tails (skins, halos, …)
    - Find new p and n halos
    - Understand development of n-skins

- **PUMA at AD**
    - Where to find p̄? => AD
    - Transporting p̄ from AD to ISOLDE? => There is no connecting beam line between the 2 facilities, so the requirements are:
        - A transportable ion trap with sufficient storage capabilities (10E9 p̄)
        - XHV vacuum conditions for the storage of p̄
        - A detection system for monitoring annihilation rates during the transport
        - A very soft, slow transport
    - Good news: long p̄ trapping time already achieved (ex. BASE: > 400 days, S. Sellner et al., New J. Phys. 19 083023, 2017). However, the lifetime with p̄ plasma is less known. The example of the successful transportation of trapped e- in the US (from the West to the East coast) was reported. For the transportation from AD to ISOLDE, the technical choice was made to have a cold mass to maintain the trap at 4K when transported, which requires 25 days of cool down.
    - Some numbers
        - ~ 1.5E13 p from the PS at 26 GeV/c onto a target generate ~ 3E7 p̄ in AD
        - Deceleration of p̄ down to 5.3 MeV in AD and down to 100 keV in ELENA (since 2018)
        - Duty cycle of ELENA: 4 x 4E6 p̄ bunches every 110s => Possibility to use 100 keV p̄ every 20s
        - Deceleration of p̄ from 100 keV to 4 keV by Pulsed Drift Tube (PDT) after the wall to experiment hall
    - First experimental campaign with stable isotopes from gas ion source
    - Dedicated beam line: mass separation with Multi-Reflection Time-of-Flight Separator, stacking and cooling in Paul Trap
- **PUMA at ISOLDE**
    - Radioactive ion beam production at ISOLDE
        - High energy (1.4 GeV) p are impacted onto a thick target (e.g. 238U, 232Th, 208Pb, 139La, …)
        - The p split up the heavy nucleus in one of three ways
            - Fission
            - Fragmentation
            - Spallation
    - The new RC6 transfer line
        - Deceleration and accumulation of RIBs in RFQ cooler buncher Paul trap
        - Isobar separation for beam purification in Multi-Reflection Time-of-Flight Separator

  - Re-acceleration to 30 keV for beam transport
  - Deceleration with pulsed drift tube and injection into PUMA

- **Summary and Outlook**
  - PUMA is a new experiment at CERN accepted in 2021
  - It aims at bringing together low-energy p̄ and unstable nuclei to probe the tail of the nuclear density distribution
  - Observable: neutron-to-proton-ratio, which allows investigation of nuclear phenomena like Halo nuclei and neutron skins of stable (ELENA) and exotic isotopes (ISOLDE)
  - Transport of p̄ from ELENA to ISOLDE
  - First p̄ in PUMA experimental zone since November 2022: operation of 96kV PDT confirmed
  - Offline ion source beamline fully commissioned
  - First experiments at ELENA and construction of RC6 beamline at ISOLDE envisaged for 2024
  - First low-energy RIB experiments at ISOLDE in 2025 before LS3

Q&A session / discussion

- Q1 about the main topics, which is a measurement: which accuracy can be measured? A1: accuracy envisioned to be 10% (it is not a precision experiment). For the neutron skins it will be more difficult.
- Q2: how much physics can be done at the AD facility? A2: quite a lot (see slide 17).
- Q3: what is the typical lifetime of p̄ in the trap at the moment? A3: it can be very long (> 400 days, as mentioned in the talk) and they need 20-30 days of lifetime for the PUMA experiment campaign.
- Q4: why the road is so long to go from ELENA to ISOLDE? A4: it has been chosen to limit inclination and minimise transport risks.
- Q5: what are the dimensions of the detector setup on slide 14? A5: the detector is ~ 30 cm long, the inner is 27 cm, the bars are few mm to cm.
- Q6: is there any special mechanical device used for the transport to improve stability of the trap? A6: Yes, Lukas suggests to have a deeper look into the technical report
- Q7: what are the charge and energy from ISOLDE? A7: ions from ISOLDE are (normally) single charge and with an energy of 30 keV
- Q8: from slides 14, it seems the particle detector assumes only pions come out. Are there other particles produced? R8: yes, there will be mostly pions produced but also some kaons.

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