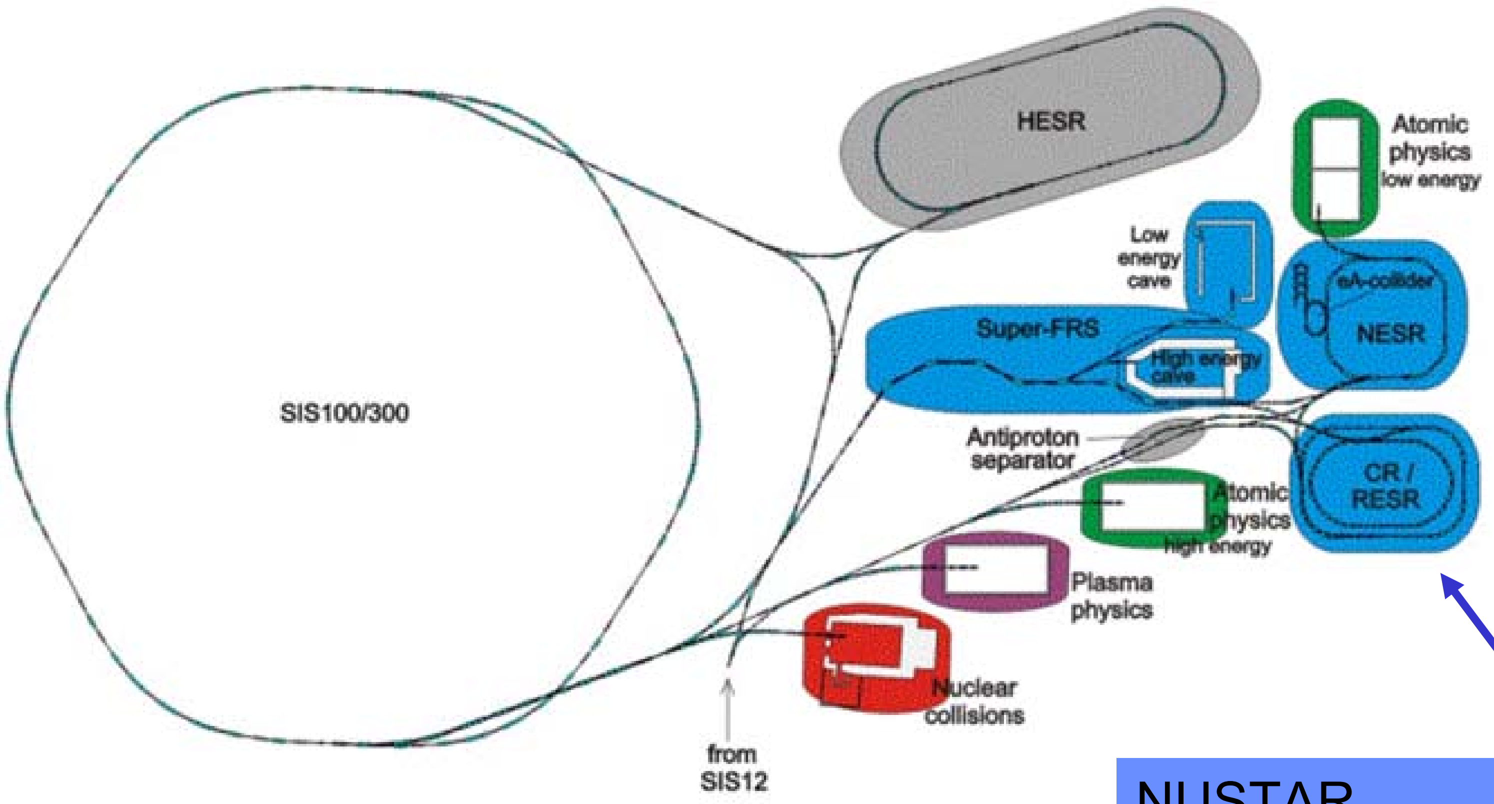
Antiprotonic exotic nuclei at FAIR

* The Super-FRS, the NUSTAR facility at FAIR

* Motivation for anti-protonic exotic nucei

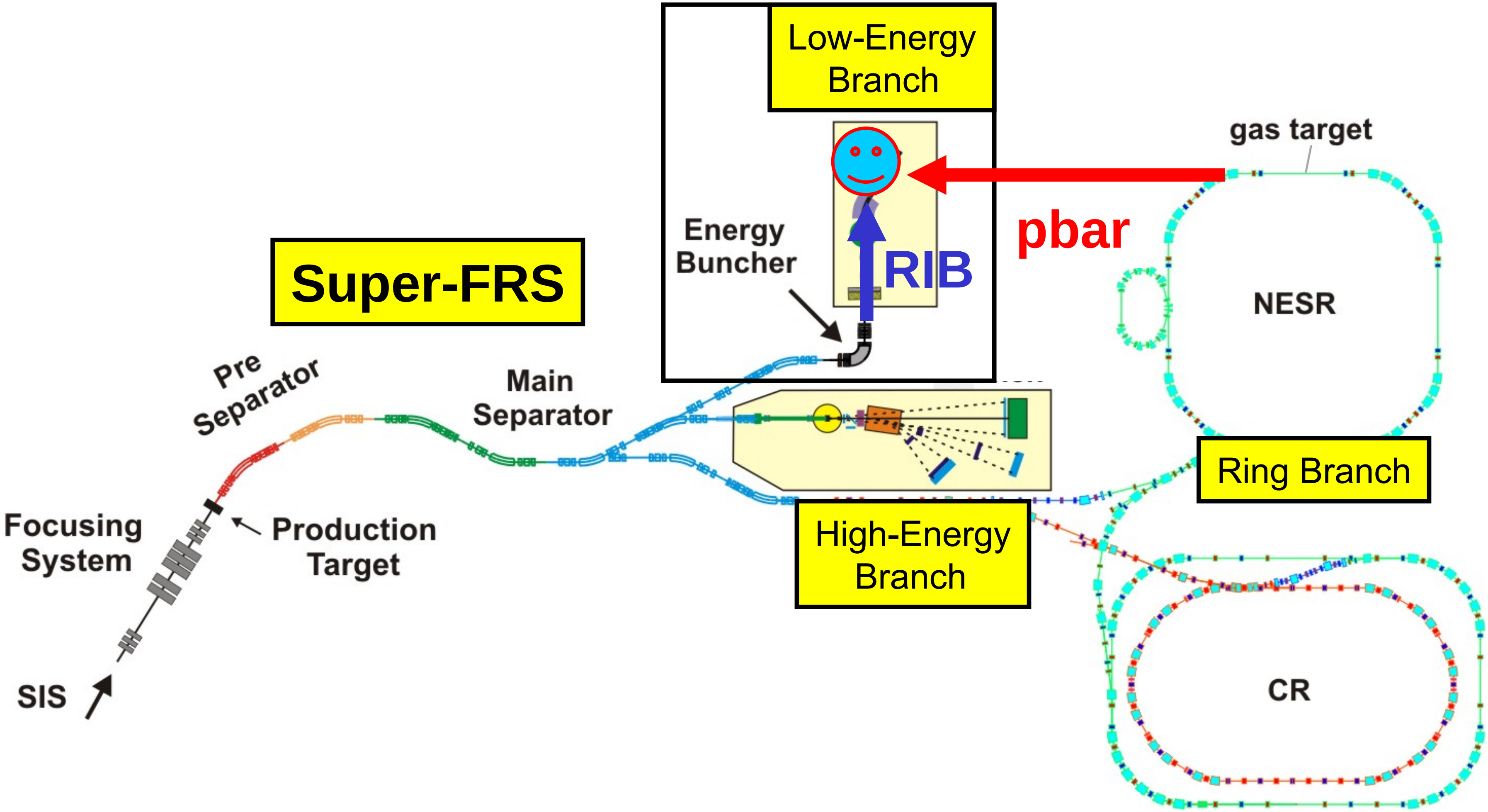
* Production and observables

FAIR
The international <u>**F**</u>acility for <u>**A**</u>ntiproton and <u>**I**</u>on <u>**R**</u>esearch

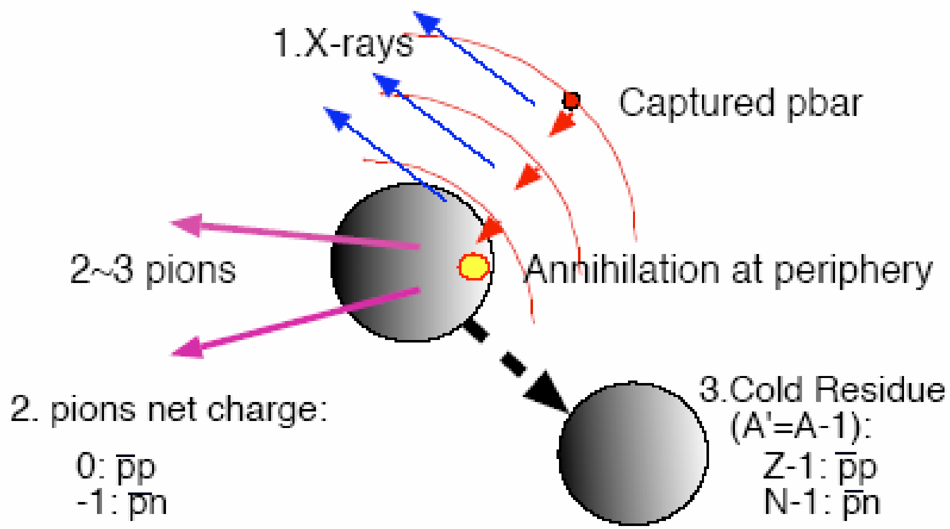


NUSTAR
<u>**Nu**</u>clear <u>**st**</u>ructure and nuclear <u>**a**</u>strophysics <u>**r**</u>esearch

The Super-FRS facility



Antiprotonic exotic nuclei



1. X-rays

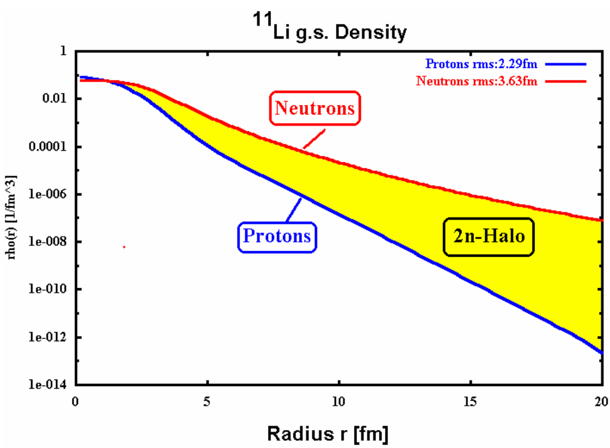
2. Net charge of pions

3. Momentum of recoil nucleus

* A new probe for nuclear structure studies of exotic nuclei

* Annihilation at $\rho \sim \rho_0 / 1000$

* Difference between annihilation with p or with n



.....well, the idea is not quite new....

Evidence for a Neutron Halo in Heavy Nuclei from Antiproton Absorption*

W. M. Bugg, G. T. Condo, and E. L. Hart
The University of Tennessee, Knoxville, Tennessee 37916

and

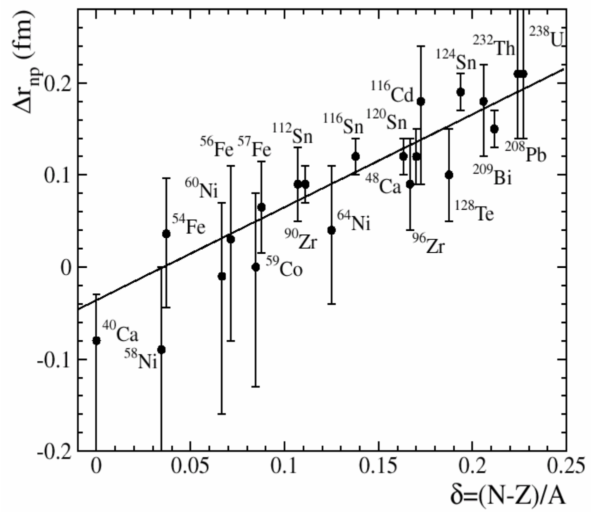
H. O. Cohn and R. D. McCulloch
Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830
(Received 19 April 1973)

From a study of stopping antiprotons in a variety of elements located in a hydrogen bubble chamber, we find evidence for the existence of a neutron fringe in heavy nuclei.

TABLE IV. "Halo factor" analysis.

Element	$N(\pi^-) - N(\pi^+)$	$N(\bar{p}n)$	$N(\bar{p}p)$	$\frac{N(\bar{p}n)}{N(\bar{p}p)}$	$\left.\frac{N(\bar{p}n)}{N(\bar{p}p)}\right\vert_c$	$\frac{N}{Z}$	Halo factor
C	2302	2586	4089	0.632	1.00	1.00	1.00
Ti	881	1067	1111	0.960	1.52	1.18	1.29 ± 0.21
Ta	1006	1276	931	1.371	2.17	1.48	1.46 ± 0.24
Pb	947	1216	534	2.270	3.59	1.54	2.34 ± 0.50

PRL 31, 475 (1973)

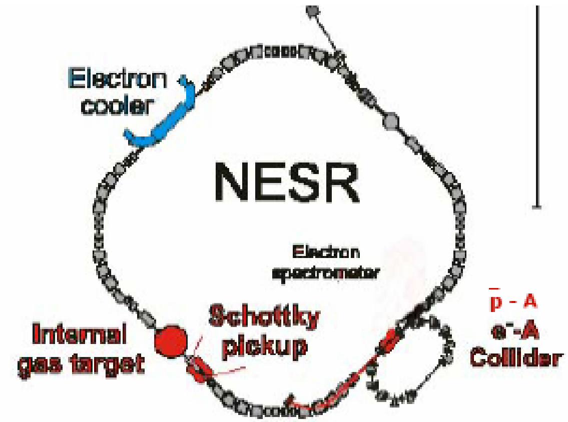


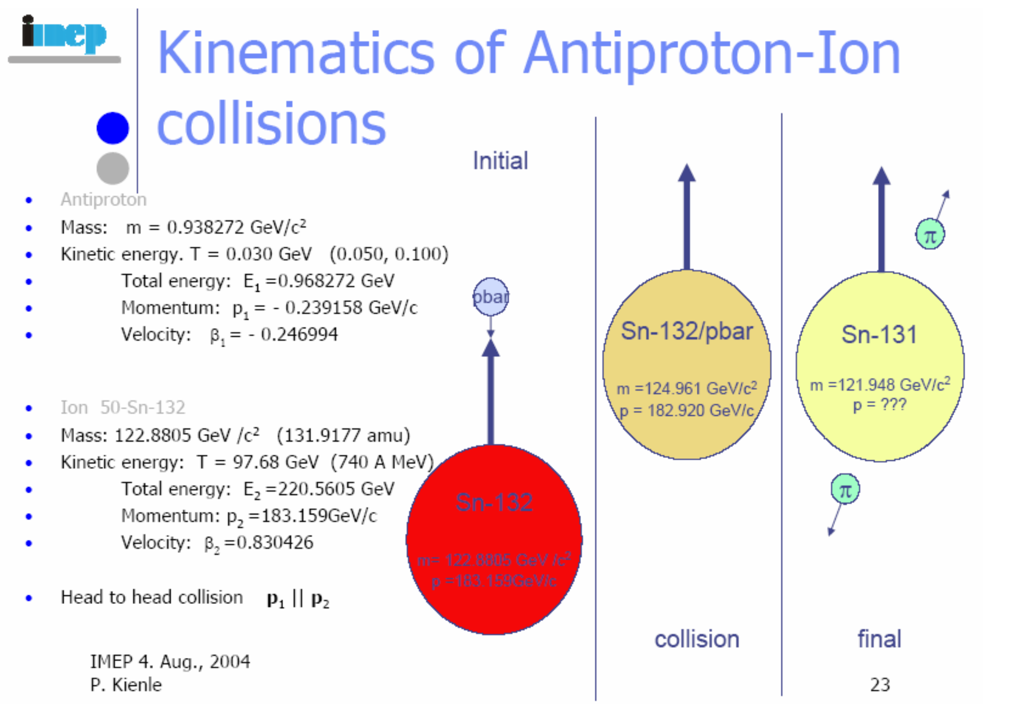
A. Trzcinska et al., PRL 87 (2001)

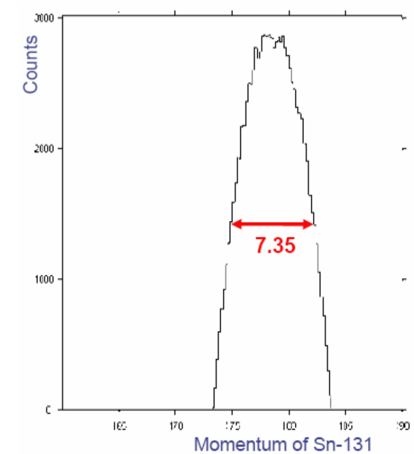
Absorption and momentum measurements

Absorption cross section at medium energies for the production of isobars

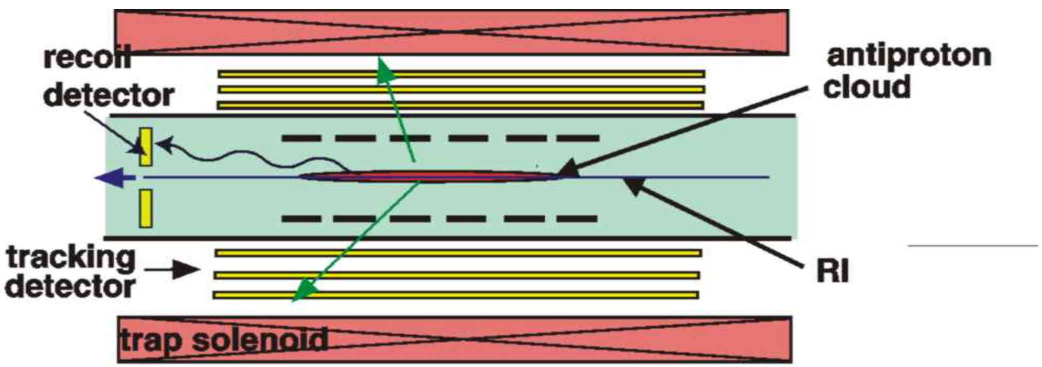
Absorption proportional to <r²> of neutrons or protons

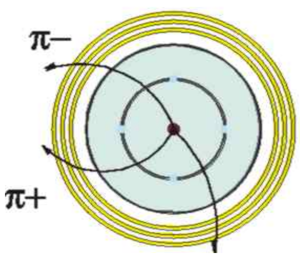


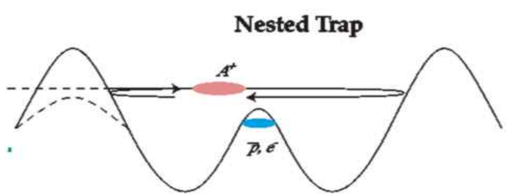




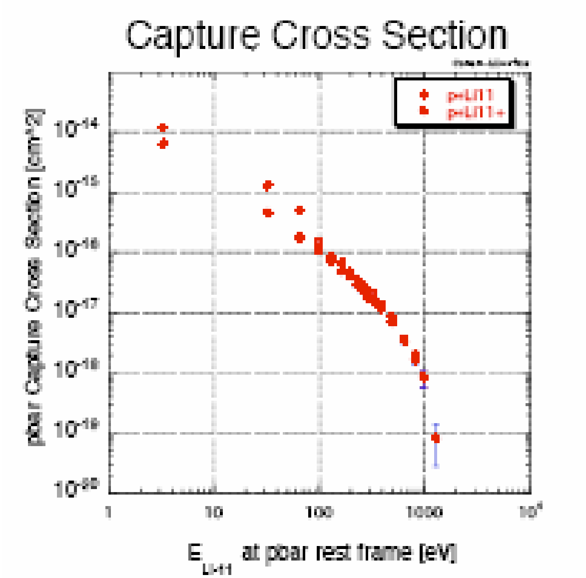
Production and yield estimate







M.Wada, Y.Yamazaki, NIM B214 (2004) 196-200



Cohen PRA69(2004)022501

$\sigma_{pbar\text{-}A} = 4 \cdot 10^{-16} cm^2$

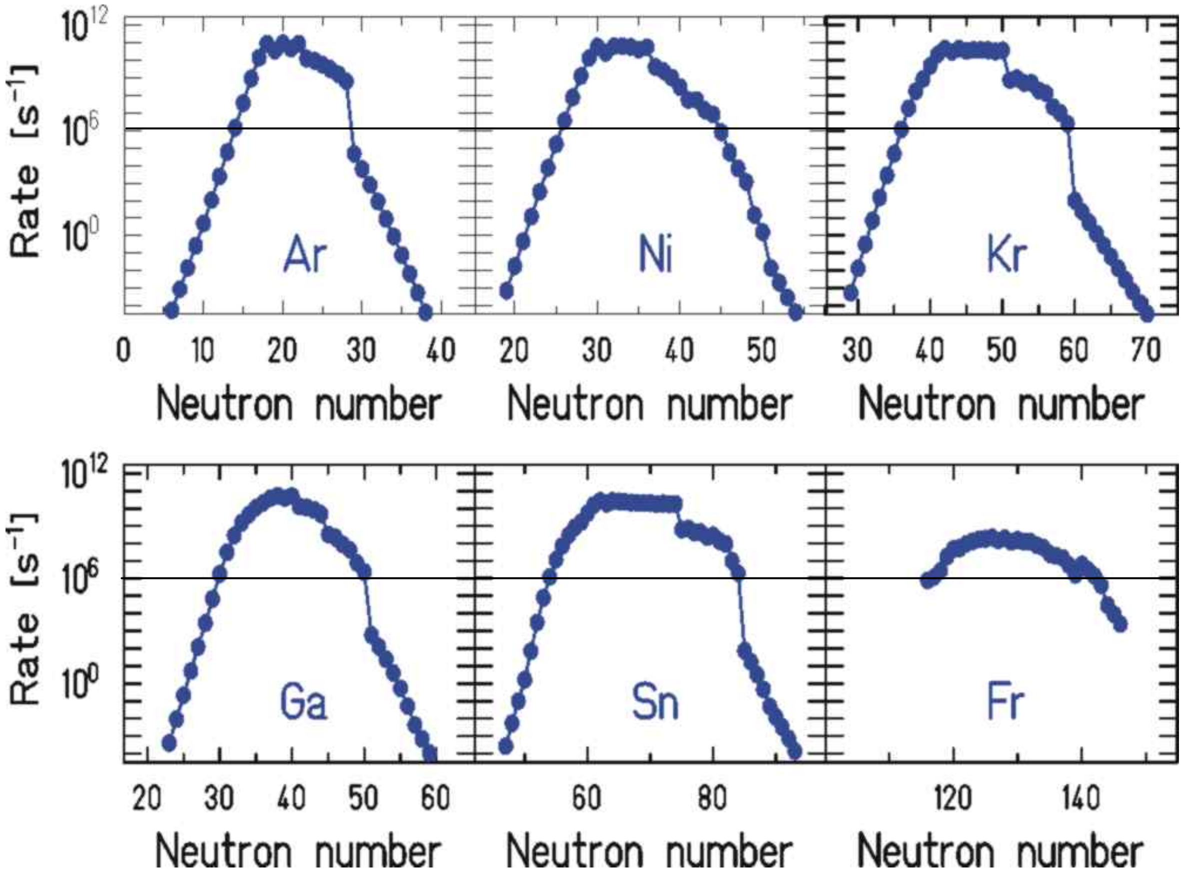
10^6 pbar, 10^3 $^{11}Li^{3+}$

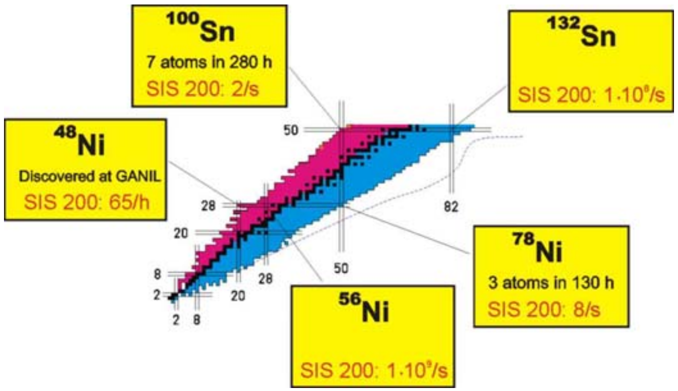
Yield = $\sigma_{pbar\text{-}A} * N_{pbar} * N_{ion}$

$\approx 10^{-2}\, s^{-1}\ \bar{p}^{11}Li$

Courtesy M.Wada (RIKEN)

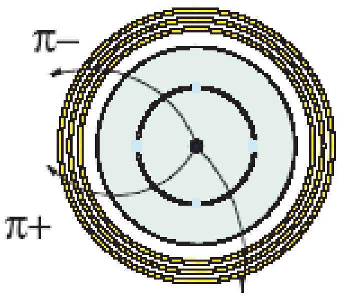
Rate estimates for selected isotopes and doubly magic nuclei





Detection method (I)

1. Pion's net charge $\bar{p}p$:0 $\bar{p}n$:−1



a) Calorimetric detection of charged pions

O I event distinguishes pbar-p or pbar-n annhilations

X Detection efficiency must be unity.

b) Comparison of statistical sum of detected pions

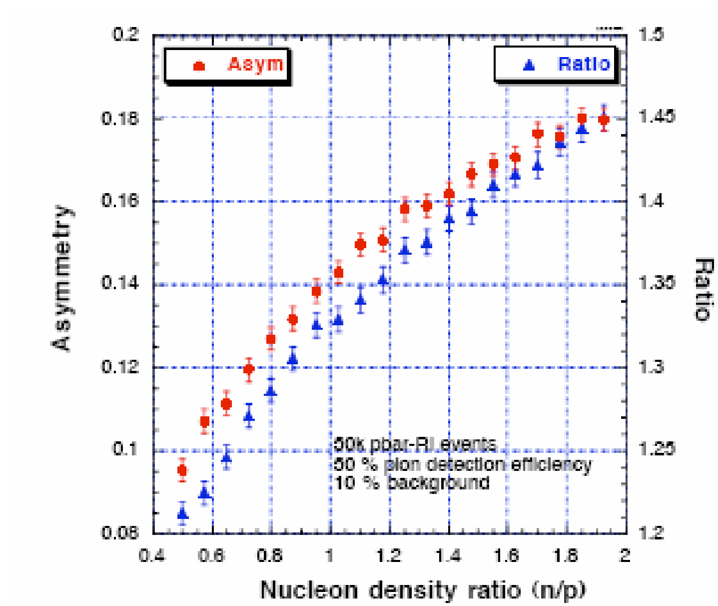
$$\frac{N(\pi^-)-N(\pi^+)}{N(\pi^-)+N(\pi^+)} \text{ or } \frac{N(\pi^-)}{N(\pi^+)} \Rightarrow \frac{N(\bar{p}n)}{N(\bar{p}p)} \Rightarrow \left.\frac{\rho(n)}{\rho(p)}\right|_{\text{@ annililation}}$$

Features:

* Universal

* High statistics needed
(50.000 events ~ 5% precision)

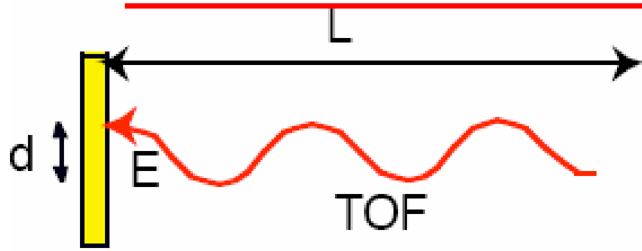
* Pion-background reduction required

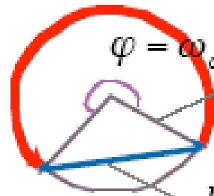


Courtesy M.Wada (RIKEN)

Detection method (II)

2. Recoiled Cold Residue $\bar{p}p: {}^{A-1}_{N}(Z-1)$ $\bar{p}n: {}^{A-1}_{N-1}(Z)$





$$\varphi = \omega_c t \qquad \rho = \frac{m|v_r|}{qB}$$

$$d = 2\rho\left|\sin\frac{\varphi}{2}\right|$$

$$d = 2\frac{m}{qB}\sqrt{\frac{2E}{m} - \left(\frac{L}{tof}\right)^2}\left|\sin\left(\frac{qB}{2m}tof\right)\right|$$

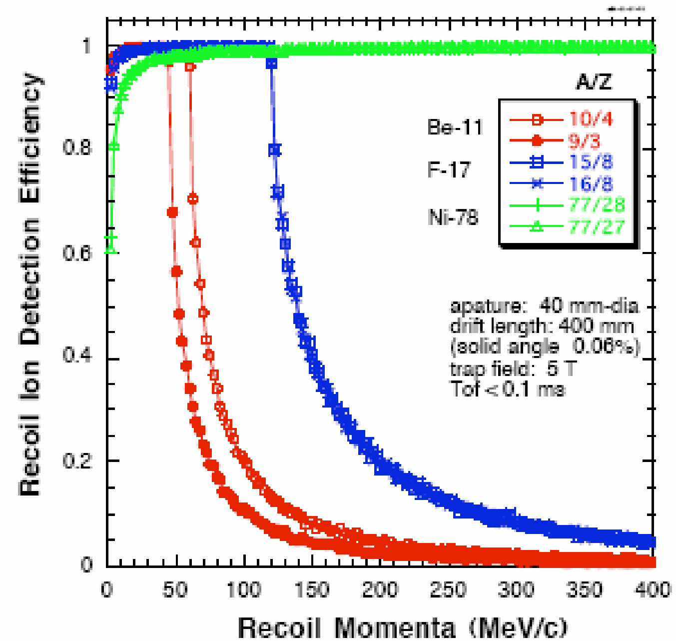
Particle Identification &
Momentum measurement

direct deduction of pbar-p, pbar-n event ratio

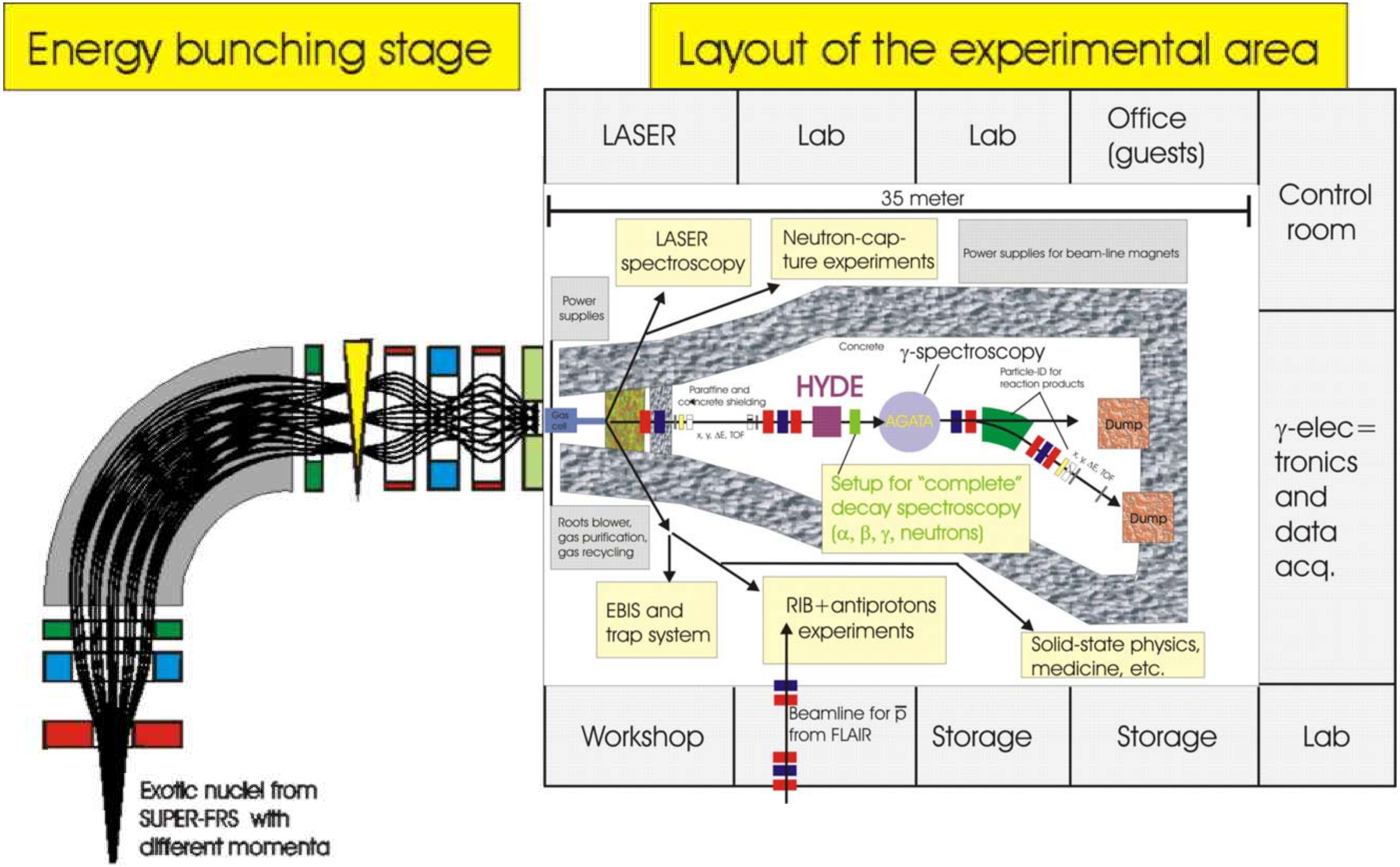
$$\frac{N\left({}^{A-1}_{N-1}Z\right)}{N\left({}^{A-1}_{N}(Z-1)\right)} \approx \frac{N(\bar{p}n)}{N(\bar{p}p)}$$

* Higher sensitivity
* Ambiguity due to nuclear excitation, re-scattering etc
* Recoil momentum ≈ **P**vanished nucleon + other effects

Courtesy M.Wada (RIKEN)



Layout of the Low-Energy Branch



Present status

- Letter of intent submitted in April 2004
- Positively evaluated in June:

Since the trapping of both anti-protons and radioactive nuclei are already possible technologically by the group, it should be encouraged to refine the proposal and also to begin the experiment with examples that are currently possible.

- Technical Proposal in preparation

Contact: M.Wada (mw@riken.go.jp)

Towards higher precision

MATS:

Precision **M**easurements using an **A**dvanced **T**rapping **S**ystem

Approved LoI for the Low-Energy Branch of the Super-FRS

The technique requires reasonable efficiency (<1%) and speed of extraction for the gas catcher. Injection and trapping of highly charged ions is an issue for that will enhance efficiency and accuracy of mass measurements.

Spokesperson: Klaus Blaum

Highly-charged ions in traps

<u>New opportunities for precision spectroscopy:</u>
* Nuclear structure studies (binding energies, Q-values)
* Weak interaction studies (superallowed β-decays, β-ν-correlations)
* Nuclear astrophysics

→ EBIT → Penning Trap

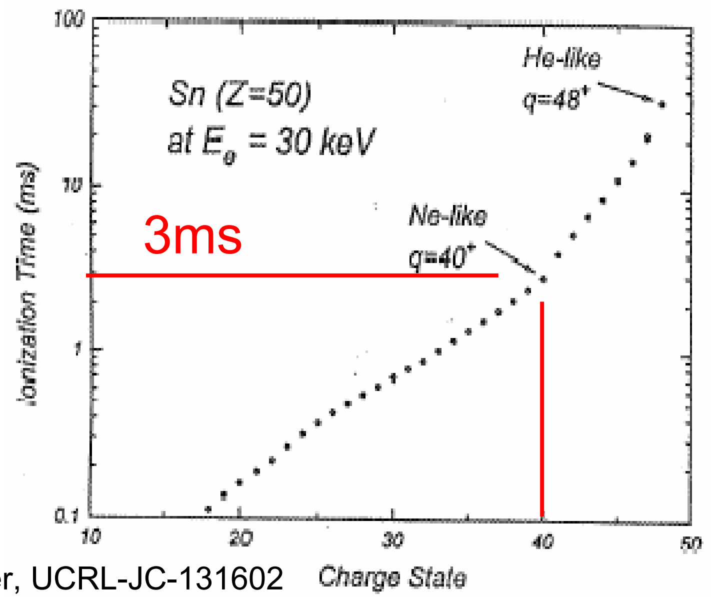
EBIT: X-ray spectroscopy

Penning Trap:
* Mass measurement
* g-factor measurement
* Decay spectroscopy

Mass measurements

higher precision ($\delta m \sim 10$ keV)

shorter half-lives ($T_{1/2} \sim 10$ ms)



R.E. Marrs and D.R. Slaughter, UCRL-JC-131602

Spectroscopy on trapped HCI

* Modification of half-lives
* Influence of electronic effects (EC, conversion,....)
* Test of Fermi's beta-decay theory
* Study of beta-decay into bound states
* Influence of electronic screening on decay properties
* Modification of energy spectra
* Influence of electron spin on decay properties (e.g. in H-like systems)

VOLUME 74, NUMBER 4 PHYSICAL REVIEW LETTERS 23 JANUARY 1995

Effects of the Hyperfine Interaction on Orbital Electron Capture

L. M. Folan and V. I. Tsifrinovich
Physics Department, Polytechnic University, 6 Metrotech Center, Brooklyn, New York 11201
(Received 12 August 1994)

Electron capture from an unfilled atomic s orbital is investigated theoretically. Analyses are carried out for two simple situations, a mirror transition of a nucleus with a nucleon in an outer $s_{1/2}$ state and a Gamow-Teller transition decreasing the nuclear spin by one unit. It is shown that the hyperfine interaction between electron and nuclear spins has a great influence on the rate of electron capture at temperatures small compared to the hyperfine splitting. The possibility of inducing electron capture with resonant electromagnetic fields is discussed.

Summary

New challenges and opportunities with trapped exotic nuclei

Antiprotonic exotic nuclei:
an interesting avenue to the nuclear periphery
experimentally and theoretically widely unexplored

Highly-charged exotic ions:
new opportunities for precision spectroscopy
complementary to storage-ring experiments

Other ideas welcome!
(.....think 10 years ahead from now!)

Rate estimates